MODALS AND MODALITY IN ENGLISH FOR ACADEMIC PURPOSES: SCIENCE AND TECHNOLOGY

BY

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DEDICATED TO

MY MOTHER

AND THE MEMORY OF

MY FATHER

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In order to study the frequency of modal occurrences and meanings in scientific and technical English as used at the graduate level in an American university for possible applications in teaching and preparing materials for foreign students studying English for Science and Technology (EST), six hours of classroom lectures (in the fields of computers, engineering, and medicine) and a comparable amount of data from reading assignments for these classes were analyzed according to the framework developed by F.R. Palmer in Modality and the English Modals.

The 80,000 word data base yielded about 1550 modals, 1100 spoken and 450 written. About 23 percent of the finite verb phrases in the spoken data contain modals and 16 percent in the written data. The most common spoken

modals in these data are *can*, *will*, *could*, *going to*, and *have to*. The most common written modals in these data are *may*, *can*, *should*, *will*, and *must*. The most common spoken meanings are dynamic (those which indicate that an event is possible or necessary or that the subject has the ability or willingness to do something), futurity, conditionality and unreality, and epistemic (judgments about propositions). The most common written meanings are dynamic, epistemic, instructional, and nonfactivity.

Possible application of these findings to teaching and preparing materials for EST are discussed.

Transcriptions of the classroom lectures are provided in the appendices.

CHAPTER I
INTRODUCTION

Modals and EST

L. Fillmore (1976:81) has suggested that "the English verbal element which has the greatest number of surprises in store for the second language learner is the modal system." Cohen et al. (1979:556) have indicated that interpretation of modals is a problem which cuts across disciplines for students using English for Academic Purposes (EAP). The purpose of the present study is to carry out a contextual analysis (along the lines of Celce-Murcia's 1980 discussion) of oral and written English for Science and Technology (EST), a subdivision of EAP, in order to determine which modals and modal meanings are used and if any are more frequent than others. The data base consists of 80,000 words, half spoken and half written, collected from first semester graduate courses in computer sciences, engineering, and medicine at the University of Florida.

Foreign students in the United States must confront EAP. The following table indicates the fields of study in which these 311,880 students enrolled during the 1980/81 academic year (Boyan 1981:6):

Table 1-1
Distribution of Foreign Students by
Field of Study 1980/81

Field of Study	Number	Percent
Engineering	80,470	25.8
Business and Management	54,380	17.4
Undeclared	25,150	8.1
Social Sciences	24,310	7.8
Natural and Life Sciences	23,030	7.4
Mathematics and Computer Sciences	19,180	6.1
Fine and Applied Art	15,450	5.0
Intensive English Language	14,050	4.5
Humanities	13,070	4.2
Education	11,980	3.8
Health Professions	11,320	3.6
Other	10,830	3.5
Agriculture	8,660	2.8
Total	311,880	100.0

Thus the three areas of investigation in this study--computer sciences, engineering, and medicine--account for 110,970 or about thirty-five percent of the foreign students in the United States during the 1980/81 academic year.[1]

There has been some controversy in the past as to whether or not EST should be treated as a separate entity. The questions now, however, center around determining just what the characteristics of EST are and how EST differs from other uses of English. Britton (1975:10-11) has grouped definitions of technical writing into four categories: 1) those which define it in terms of subject matter; 2) those which define it in terms of word order, sentence characteristics, vocabulary, and style; 3) those which define it in terms of the kind of thought process; and 4) those which define it in terms of its purpose.

He proposes (11) "that the primary, though certainly not the sole, characteristic of technical and scientific writing lies in the effort of the author to convey one meaning and only one meaning in what he says." Strevens (1978:193) suggests that scientific language does not differ from other uses in its basic components but in "the statistical properties of the mixture in which they occur, and the intention, the purpose behind their selection and use."

If we wish to do anything to facilitate the foreign students' interpretation of modals in EST, the modals must be studied in context. Celce-Murcia (1980:44) states that "contextual analysis begins with the identification of a form or forms and then sets out to uncover as much information as possible regarding the meaning, function, and frequency of the form(s)." The type of discourse chosen for analysis would depend on the researcher's purpose.

The need for this type of analysis is becoming more and more apparent. According to Celce-Murcia (1980:46), "most language methodologists would agree that the proponents of the deductive-cognitive approach to language instruction have now taken momentum away from the proponents of the inductive-behaviorist approach." Thus English as a Second Language (ESL) teachers need rules or generalizations about language not necessarily found in reference grammars or ESL textbooks. Celce-Murcia (48) emphasizes that what must be kept in mind is "that the

rules of English usage should not be based on intuitive, theoretical hypotheses but on fact (i.e., empirical data derived from valid tests, relevant samples of uncontrived written and spoken discourse)."

Definitions of modals tend to be somewhat circular. Modal is a grammatical term which refers to the auxiliary verbs which express modality. Modality is a semantic term which Palmer (1979:4) regards as "relating to the meanings that are usually associated with mood." Lyons (1972:307) says mood "is best defined in relation to an 'unmarked' class of sentences which express simple statements of fact, unqualified with respect to the attitude of the speaker towards what he is saying." He goes on to suggest that sentences 'marked' for mood indicate "the speaker's commitment with respect to the factual status of what he is saying (his emphatic certainty, his uncertainty or doubt, etc.)"

It should be kept in mind that the modals are not the only group of words in English which express modality. Hermeren (1978a:10) gives the following examples of nouns, adjectives, adverbs, and verbs which are used for this purpose:

A. NOUNS such as chance, hope, presumption and expectation ('There is no chance etc. that he will succeed'); intention and determination ('His intention etc. to learn English is admirable).

B. ADJECTIVES such as conceivable, possible, likely and obvious; appropriate and necessary which can all occur in the impersonal construction 'it is . . . that . . .'. Other adjectives, such as sure and surprised, occur in a personal construction like 'I am . . . that . . .', whereas adjectives such as able and willing occur in the construction 'I am . . . to . . .'. A third group of adjectives, such as doubtful and certain, can occur both in a personal and impersonal construction.

C. ADVERBS such as hardly and perhaps ('He will hardly etc. go there'); evidently, assuredly, fortunately, regrettably, surprisingly and strangely ('Evidently, etc. he was a dangerous criminal').

D. VERBS:

1. MAIN VERBS like doubt, think, believe and predict ('I doubt etc. that he will win'); suggest ('I suggest that he should have an apple'); want, prefer, desire, permit and forbid ('He wants etc. me to win').

2. MODALS, i.e. shall, should, will, would, can, could, may, might, must and ought.

Various approaches have been taken in modal studies. The research all seems to support Lakoff's (1972:229) statement, "The definition and description of modality has been one of the most pervasive and persistent problems in linguistics, spilling over as well into related disciplines such as philosophy." Modals have been a point of contention in theoretical discussions during the last twenty-five years. The controversy has centered around the question of whether they should be analyzed as auxiliary or main verbs. Pullum and Wilson (1977) provide a critical review of this controversy.

In the remainder of this chapter, some of the approaches will be summarized. A short historical sketch will be followed by discussions of representative articles dealing with modals from the points of view of form, semantics, pragmatics, and a syntactic-semantic paradigm.

Historical Development

The historical development of the various modals is quite complex. Lightfoot (1979:81) uses English modals as an example to show "that grammars can undergo radical restructurings in the course of time. . . ." According to Lightfoot (101), there were several early, apparently isolated, changes in premodals, members of "an inflectional class generally known as 'preterite-presents'" which developed from preterites which "had taken on present meaning in pre-Germanic." These changes included, for example, loss of ability to take direct objects, loss of "all the non-premodals in this class," and changes involving word order (101-9). Other changes, such as loss of ability to appear in infinitival constructions and limitation to one modal per verb, occurred around the same time during the sixteenth century (110-3).

It is indeed a complex task to trace the historical development of this group of words. In discussing could for example, Moore (1951:172) suggests that "the early Modern English strong form was [ku:ld]; this form was not derived from Middle English [ku:də] but developed under the influence of early Modern English [ʃu:ld] and

[wu:ld]. . . ." Need is another example of bizarre history. According to Moore (173), "it is by no means clear why this verb developed the uninflected form, but it seems to have been (at least in part) from the analogy of the preteritive-present verbs. . . ." The modals have such a diversified history that Lightfoot (1979:103) states that "it does seem impossible to define a class of modals . . . on semantic grounds."

Block 1947

Block (1947:399) attempts to take the extensive descriptions by scholars such as Sweet, Palmer, Curme, Fries, Jespersen, and Hockett and "arrange the known facts more systematically than has been done before, or in a way that will be more useful to other linguists." As a result of his work, Block (403) classifies verbs into seven inflectional classes.

The modals fall into the two categories considered as auxiliaries. The first of these consists of verbs such as can which have a zero suffix for the third person singular in the present and a /d/ suffix for the preterite, e.g. could. The second auxiliary category is made up of verbs such as must with a zero suffix for third person singular in the present and uninflected with respect to the preterite, participles, and gerunds. Block's classification system is based on form, and he includes better, as in he better go, in the category with must (409).

Boyd and Thorne 1969

The Boyd and Thorne study (1969:57) proposes "an analysis of the semantic structure of modal sentences in English." They base their study on work by Austin concerning speech acts, e.g. promising, betting, naming. Boyd and Thorne (58) incorporate the idea of speech act and illocutionary force from the point of view "that a complete account of meaning of a sentence cannot be restricted to semantic analyses as these are usually understood and that they must be extended to include information about the kind of speech act involved in uttering the sentence--that is its illocutionary force." In order to analyze sentences like You will go, they postulate two sentence elements: one carries the "illocutionary potential" and the other "propositional content" (59). Illocutionary potential refers, for example, to whether the sentence is an imperative, a promise, or a statement. In this framework, modals are analyzed as "indicating the illocutionary potential in the sentences in which they occur" (62). Will, shall, should, must, may, can, might, and could are considered with this in mind.

This approach allows for the close relationship found between some sets of modal and nonmodal sentences as in these examples (Boyd and Thorne 1969:62):

He goes to London tomorrow.

He will go to London tomorrow.

The first example is considered to be a statement while the

second is considered a prediction. "But in this case the illocutionary force of utterances is the same, or nearly the same--as it is indeed in any case where the propositional content of a statement and a prediction is an identical present tense sentence containing a future time reference expression" (63).

Lakoff 1972

Lakoff (1972:229-30) expands the considerations to be taken into account when dealing with modals even further:

> In order to define the class of modals, or to provide the set of environments in which a modal may be correctly or appropriately used, one must refer to many levels of language: the purely syntactic environment, as we know well; the logical structure, as we also know; and (which ought not to come as a surprise, but may still be one) the context of the utterance: the assumptions that are shared by speaker and addressee, whether or not previously given linguistic expression in the discourse; the social situation assumed by participants in the discourse; and the impression the speaker wants to make on the addressee; and so on.

This outlook probably provides us with a more realistic idea of just how many factors we must deal with. One of the problems Lakoff discusses (230) is that "of partial equivalence, or incomplete synonymy, between two modals, or between a modal and an apparent paraphrase." She suggests that contextual features may sometimes provide the explanation.

Lakoff's study does not set up a framework to deal with modals, but it does raise many questions involved in explaining modals.

Marino 1977

Marino (1977:73) suggests a possible paradigm for modals, though he stresses that "we are only at the beginning of an adequate syntactico-semantic description of the formal and conceptual aspects of the modal system." He also discusses the difficulties in defining modals and determining just what falls into this group. He suggests that "there appears to be a hard structural and semantic core of modality from which many types of occurrences diverge in varying structural and semantic ways" (76). His study focuses on "the core semantic characteristics of the paired modals" in terms of epistemic and root modals (78). "In general, the root occurrences must be understood to involve the speaker's modal perspective on the subject of the sentence and the epistemic occurrences refer to the speaker's modal perception on the whole proposition" (79). The paradigm he suggests is the following (87):

MODAL	CORE MEANING	PAST FORM
root <u>can</u>	capacity	<u>could</u>
epistemic <u>can</u>	propositional capacity	<u>can</u> + perfective
epistemic <u>could</u>	conditional propositional capacity	<u>could</u> + perfective
root <u>may</u>	permission	semantically blocked
epistemic <u>may</u>	propositional possibility	<u>may</u> + perfective
epistemic <u>might</u>	conditional propositional	<u>might</u> + perfective

root shall	promissory intent	semantically blocked
epistemic shall	emphatic propositional future	semantically blocked
epistemic should	conditional propositional entailment	should + perfective
root will	determination	would
epistemic will	definite propositional future	semantically blocked
epistemic would	implied negation	would + perfective

This Study

In Chapter II, three data based studies will be discussed in detail. Joos 1964 is based on spoken data, Ehrman 1966 on written data, and Palmer 1979 on both spoken and written data.

A description of the data collection and procedures for analysis of form and meaning in this study is presented in Chapter III.

The results of the analyses of form and meaning as found in the data are presented in Chapters IV and V, respectively.

Chapter VI contains a discussion of possible applications of the findings and suggestions for further research.

The study and findings are summarized in Chapter VII.

Note

1. The three areas studied have been selected because they are of particular interest to the students I work with at Bayamon Technological University College.

CHAPTER II
DATA BASED MODAL STUDIES

Joos 1964 and Ehrman 1966 are probably the most commonly referred to data based studies of modals. The Joos study uses the transcript of a British trial while Ehrman uses the Brown University corpus.[1] Thus, the former is based on spoken British Enlish whereas the latter is based on written American English. A brief treatment of each of these studies will be followed by a detailed discussion of a more recent study, Palmer 1979, which is based on the spoken and written corpus of the Survey of English Usage.[2] Both the Joos and Ehrman studies concentrate on what the different uses of a given modal have in common. The Palmer analysis deals with this but also provides for distinguishing the different uses.

Joos 1964

Joos 1964 is a detailed study of the English verb system. The data he uses are from a 1957 murder trial which is available in the book The Trial of Dr. Adams by Sybille Bedford (1959). The last chapter of the Joos study is devoted to modals.

According to Joos (1964:149), factual assertions have truth value, but in relative assertion "there is no such truth-value with respect to the occurrence of the

event; what is asserted is instead a specific *relation* between that event and the factual world, a set of *terms of admission* for allowing it real-world status." These relations are expressed through modals.

Joos (1964:166) suggests the existence of two competing modal systems. In the modern system, each modal has three meanings: *adequate* or *contingent*, *casual* or *stable*, and *assured* or *potential*. These meanings are discussed in the following manner (149-50):

> Casual modals . . . *take* that relation from the minimal social matrix of events, where the determining factors are the result of chance and whim operating upon the items that populate the factual world of accepted reality; but the
> Stable modals . . . find that relationship in the maximal social matrix of events, where the determining factors are eternal and omnipresent: they are community mores. Accordingly, stable modals exclude remote tense.
> Adequate modals . . . derive their force from *completeness* in the set of determining factors; but the
> Contingent modals . . . get their weakness from some *deficiency* in the determining factors.
> Assurance . . . comes from *penalties* for failure of the specified event to occur; but
> Potentiality . . . comes from *immunity* in case the actor brings the event to completion.

The modals are thus classified in the following manner:

Table 2-1
Joos' Classification of Modals

Meanings	Modals						
	will	*shall*	*can*	*may*	*must*	*ought to*	*dare*	*need*
Casual	xx	xx	xx	xx				
Stable					xx	xx	xx	xx
Adequate	xx		xx		xx		xx	
Contingent		xx		xx		xx		xx
Assurance	xx	xx			xx	xx		
Potentiality			xx	xx			xx	xx

Would, should, could, and might are considered to be remote tense forms and are explained by contrasting them with the remote tense as used in factual assertion. "In factual assertion, remote tense blots out present reality; with modals (in relative assertion) remote tense does this only part way. . . . the remote tense of a modal generalizes so that present reality becomes a minor fraction of the total possible reference" (169).

Along with this modern system, there is an archaic system which still influences modal meaning. These archaic meanings are especially influential in the use of shall, should, may, and might. Shall and should may carry meanings of "subservient probity" making "a faithful promise good for all time" (Joos 1964:168). May and might in the archaic sense may carry the idea of "subservient freedom" indicating that "the event is authoritatively allowed, and the assertion is worded with this modal to signify that the actor is hardly free to desist" (187).

Joos' (1964:148) presentation of his analysis as dealing with "the complete solidarity and symmetry of the English system of modal markers for relative assertion" has led to much criticism of this model. (See, for example, Hermeren 1978).

Ehrman 1966

Ehrman (1966:9) "began with the question of whether or not Martin Joos' semological classification of modal auxiliaries . . . is valid, especially for American English."

Using a selection from the Brown University corpus, she (10) wanted to find "the most general meaning(s) for each modal that would apply to as many occurrences as possible." Therefore, she discusses the modals in terms of basic meaning, "the most general meaning of the modal in question, the meaning that applies to all its occurrences," and overtones, "subsidiary meanings which derive from basic meaning but which add something of their own" (10).

Ehrman (1966:74) concludes that the modals have the following meanings:

Can: nothing in the state of the world prevents the predication:

A. there are certain positive qualities of the subject such that the way is cleared for the predication;
B. no lack of permission prevents the predication;
C. nothing in the state of the world prevents the occurrence of the predication.

May: nothing in the state of the world prevents the predication, and furthermore there is no guarantee that the predication will not occur.

Will: the occurrence of the predication is guaranteed, either in a concrete (future time function) or a general (neutral time function) context:

A. subject's volition has something to do with the guarantee;
B. the predication is a natural consequence or concomitant of another factor or predication.

Shall: same as will, except used with first person subject and carries stylistic notion of education involving exposure to prescriptive grammar (this is the only current usage of shall in the corpus; in speech it is also used with second- and third-person subjects to indicate that the speaker or someone designated by the speaker guarantees the predication.)

Should-ought to:	the predication conforms to the speaker's or writer's view of some aspect(s) of the state of the world: A. the occurrence of the predication will conform to the speaker's or writer's view of the probable result of the relevant factors.
Must:	the predication is required by some aspect(s) of the state of the world: A. the occurrence of the predication is required by the speaker's or writer's view of the probable result of the relevant factors.
(Need):	the predication is required by the speaker's or writer's view of some aspect(s) of the state of the world.

Criticism of Ehrman centers around the inconsistency of saying there is a basic meaning while pointing out that may, for example, has a continuum of meanings (Hermeren 1978:26-7).

Palmer 1979

The analysis in Palmer 1979 is based on the extensive oral and written corpus of the Survey of English Usage. Since Palmer also refers to the Brown University corpus, his work seems to utilize one of the broadest data bases of any study available to date.

There are several reasons for choosing Palmer's framework as the basis for the present study. His analysis is based on both spoken and written data. He differentiates among the various meanings rather than just looking for what is common in all uses of a given modal. Palmer's work deals with English in general. By using it to analyze modals in EST we may be able to determine how EST usage differs from general usage. Further studies in other areas could be carried out using the same framework and then compared.

Palmer (1979:1) is "concerned with the semantic concept of modality, but only to the extent to which it is signalled by the English modal verbs." He assumed (8) "that the basic notions of modality are those of possibility and necessity." Taking formally defined modals as the starting point, he suggests (5) "that the meanings involved are such as to justify characterizing them as 'modality'."

Various formal criteria are used in developing Palmer's system. The first four also characterize BE, HAVE, and DO (Palmer 1979:9):[3]

> (i) Inversion with the subject. (Must I come?)
> (ii) Negative form with -n't. (I can't go.)
> (iii) 'Code'. (He can swim and so can she.)
> (iv) Emphatic affirmation. (He will be there.)
> . . . There are further specifically 'modal' criteria:
> (v) No -s form for 3rd person singular.
> (vi) Absence of nonfinite forms. (No infinitive, past or present participle.)
> (vii) No cooccurrence. (No *He may will come.)

According to Palmer (10), "these formal characteristics of the modals form a complex set, and it is plausible to suggest that they have been retained in the language only because native speakers are aware of the modals as a set. . . ." Using these seven characteristics as basic, considering the semantics, and acknowledging that "some arbitrary decisions are inevitable," Palmer (17-18) defines the scope of his study as follows:

> (i) There is no doubt about the central position of MAY, CAN and MUST. They are both formally modals and clear exponents of possibility and necessity.

(ii) OUGHT TO and SHOULD are also formally modals, and can be shown to be concerned with a facet of necessity. . . .
(iii) SHALL and WILL are included because they are formally modals, and although they do not relate to possibility and necessity they have much in common semantically with other modals. . . . Even their use for future time reference has some relation to modality.
(iv) Briefer consideration will be given to DARE and NEED, which are half in the formal system, to IS TO, and to the more marginal WOULD RATHER and HAD BETTER.
(v) USED TO will not be discussed. It has many of the formal characteristics of a modal, but it is outside the semantic system. . . .
(vi) We shall discuss in some detail BE BOUND TO, BE ABLE TO, HAVE TO, HAVE GOT TO and BE GOING TO. Formally none of these are modals, but they have an important place within the semantic system and either supplement, or contrast with, the modals.

Once the scope of his study has been stated, Palmer (18) broadens the term modal "to include all these 'modality' verbs. . . ."

Palmer suggests explaining the modal system in a two dimensional framework with degrees of modality, basically possibility and necessity, along one axis and kinds of modality along the other (1979:39). According to Palmer (36), by considering syntax and semantics, "we can distinguish between three basic kinds of modality": epistemic, deontic, and dynamic.[4] The third kind is subdivided into neutral and subject oriented. The characteristics (36-37) are in terms of marking the modality and the proposition, or event, for past and for negation and in terms of voice-neutrality as summarized below:[5]

Epistemic:		
Past	modality--no	proposition--yes
Negation	modality--yes	proposition--yes
Voice-neutrality	yes	
Deontic:		
Past	modality--no	event--no
Negation	modality--yes	event--yes
Voice-neutrality	yes	
Neutral Dynamic:		
Past	modality--yes	event--no
Negation	modality--yes	event--yes
Voice-neutrality	yes	
Subject Oriented Dynamic:		
Past	modality--yes	event--no
Negation	modality--yes	event--yes/no
Voice-neutrality	yes/no?	

It must be emphasized that the divisions are not always clear-cut. "There is no doubt that the overall picture of the modals is extremely 'messy' and untidy and that the most the linguist can do is impose some order, point out some regularities, correspondences, parallelisms" (Palmer 1979:40).

Epistemic Modality

In sentences containing modals, we can talk about the meaning associated with the modal, the modality, and the meaning associated with the proposition or the event being discussed. Epistemic modality refers to judgments about the possibility or necessity of propositions.

Epistemic possibility. Judgments about possibility are generally made in the present as in the following example (with paraphrase below):

Jim may be at home.

'It is possible that Jim is at home.'

We could make a judgment in the present about a proposition in the past:

Jim may have been at home.

'It is possible that Jim was at home.'

The proposition is marked for past through the use of have. Both the modality and the proposition can be marked for negation:

Jim can't be at home. (negation of modality)

'It is not possible that Jim is at home.'

Jim may not be at home. (negation of proposition)

'It is possible that Jim is not at home.'

Can't is used to negate the modality while may not negates the proposition.

The third criterion used by Palmer in his classification is voice-neutrality. This refers to "whether a sentence containing a modal can be passivized without changing the meaning (other than the 'thematic' meaning that may be associated with change of subject)" (Palmer 1979:34). According to Palmer (56), "sentences with epistemic modals are voice-neutral, provided that the proposition itself is voice-neutral" as in

John may have seen Mary.[6] (voice neutral)

(Mary may have been seen by John.)[7]

Might similarly expresses epistemic possibility, but it is more tentative than may:

Jim might be at home.

Jim might have been at home. (proposition in past)

Jim couldn't be at home. (negation of modality)

Jim might not be at home. (negation of proposition)

Epistemic necessity. The characteristics of epistemic necessity are very much like those of epistemic possibility. Such judgments are usually made in the present, e.g.,

> Jim must be at home.
>
> 'The only possible conclusion is that Jim is at home.'

The proposition may be in the past:

> Jim must have been at home.
>
> 'The only possible conclusion is that Jim was at home.'

The negation of epistemic necessity is a bit more complicated than that of epistemic possibility. The modality may be negated with needn't and the proposition with mustn't:

> Jim needn't be at home.
>
> 'That Jim is at home is not the only possible conclusion.'
>
> Jim mustn't be at home.
>
> 'The only possible conclusion is that Jim is not at home.'

Epistemic necessity is negated in this manner when "it is important to make the judgment in terms of necessity rather than possibility: (Palmer 1979:54). According to Palmer, it is more usual to negate epistemic necessity in terms of the logically equivalent forms of epistemic possibility: not-necessary is logically equivalent to possible-not, and necessary-not is logically equivalent to not-possible.

Thus the more usual corresponding form for negation of modality in terms of possibility:

Jim _may_ not be at home.

The more usual form for negation of the proposition in terms of possibility would be:

Jim _can't_ be at home.

The general statement that epistemic modals are voice-neutral holds for epistemic necessity:

John _must_ have seen Mary.

(Mary _must_ have been seen by John.)

Should would be "the unreal or tentative marker of epistemic necessity" in the sense that "it expresses rather extreme likelihood, or a reasonable assumption or conclusion. But it implicitly allows for the speaker to be mistaken" as in (Palmer 1979:49):

You _should_ be meeting those later on this afternoon.[6]

Palmer (55) found "no clear examples of epistemic _shouldn't_," but he suggests that perhaps

Well, that shouldn't be hard.[6]

is an example with the proposition negated.

Also expressing epistemic necessity is BE BOUND TO:

Jim _is bound to_ be at home.

Compared to the use of MUST above, this "is the more certain, and indeed can almost be paraphrased by 'it is certain that' . . ." (Palmer 1979:45). Although BE BOUND TO may be used with present reference, in the examples noted by Palmer (45), "the main verb is a verb relating to the

future and, in most cases, a verb of action" while MUST "will not normally be used to refer epistemically to the future. . . ."

Both HAVE GOT TO and HAVE TO are considered as "'necessity' modals," but only rarely do they occur in the epistemic sense (Palmer 1979:46,52):

> You've got to be joking.[6]
>
> It had to be there--there wasn't anywhere else it could have been.[6]

Epistemic reasonability or confidence. WILL used epistemically "refers to what it is reasonable to expect" or "expresses a confident statement" (Palmer 1979:47):

> Tell him Professor Cressage is involved--he will know Professor Cressage.[6]
>
> The French will be on holiday today.[6]

The tentative form is would (48):

> I think it would be Turner as well.[6]

Epistemic modality--questions. Though it is seldom questioned, Palmer (1975:56) notes examples of both direct and indirect questioning of epistemic modality:[8]

> Can they be on holiday?[6]
>
> I was wondering if it could have been fear?[6]

Can or could is used to question epistemic possibility, and "it seems that MUST, NEED, BE BOUND TO can all be used" to question epistemic necessity (56):

> Must they be on holiday?[6]
>
> Need they be on holiday?[6]
>
> Are they bound to be on holiday?[6]

Deontic Modality

Deontic modality is essentially discourse oriented, concerned with the speaker and the hearer. It deals with matters such as permission, obligation, stating an undertaking, promises, and threats. It involves the modality of an event rather than a proposition.

Deontic possibility. "Deontic possibility consists essentially in the giving of permission" (Palmer 1979:59). Both MAY and CAN are used in this manner:

> You may go to the movie.
>
> You can go to the movie.

According to Palmer (60), "evidence from the Survey is insufficient to prove the differences between MAY and CAN . . ., but it seems clear that MAY is far more formal than CAN. . . ." Both are used in idiomatic expressions:

> You can say that again.[6]
>
> You may rest assured.[6]

Commands, "often of a brusque or somewhat impolite kind," are often expressed by CAN (60):

> I'm Dr. Edgton now, so you can observe my new status.[6]

In speaking, we do not give permission "in the past or in relation to past events," and, thus, deontic possibility marks neither the modality nor the event for past (Palmer 1979:67).

In expressions of deontic possibility, both the modality and the event may be negated. "One can give

permission, etc. for an action not to take place or one can refuse permission, etc. for it to take place" (Palmer 1979:64). An example of the negation of the modality would be:

> No, you _may_ not go to that movie.

The event can be negated through stress.

> I was under the impression that you were going. But if you want to stay home, you _may_ nót go to the movie, if that's what you want.

Negation with CAN is similar:

> No, you _can't go_ to that movie. (negation of modality)

> You _can_ nót go to that movie. (negation of event)

The issue of voice-neutrality is not clear-cut. "If one gives permission, etc. for someone to perform an action, one equally gives permission for the action to be performed" (Palmer 1979:68):

> Yes, you _may_ eat the cake.

> Yes, the cake _may_ be eaten.

In the following example, however, permitting John to meet Mary is not necessarily the same as permitting Mary to meet John:

> John _may_ meet Mary.[6]

> Mary _may_ be met by John.[6]

Might and _could_ are used in a manner parallel to MAY and CAN, but they are "more diffident or polite" (Palmer 1979:68):

Might I come in, at the moment, on this, Chairman?[6]

Well, could we go on to modern novels, then?[6]

Deontic necessity. MUST is considered to indicate deontic necessity when it indicates that "the speaker (or writer) clearly takes responsbility for the imposing of the necessity" (Palmer 1979:61):

> I've been telling Peter, as I've been telling several people, you know, "You must get into permanent jobs," and I've been urging Peter to go back to school teaching or something, where he's very, very good.[6]

As with deontic possibility, deontic necessity marks neither the modality nor the event for past.

Needn't is used to negate modality in deontic necessity (Palmer 1979:64):

You needn't take this down.[6]

The event is negated with mustn't (64), which "lays an obligation not to act."

You mustn't put words in my mouth.[6]

Voice-neutrality is somewhat questionable with respect to deontic necessity. Palmer notes some examples where voice-neutrality does seem to be present, as in (1979:68):

> This, of course, must not be taken as a reason for drawing more cheques.[6]

But he also notes that in the following examples (68),

John must meet Mary.[6]

Mary must be met by John.[6]

"if I compel John to meet Mary, I do not compel Mary to be met by John."

Deontic use of SHALL. SHALL is considered as indicating a degree of deontic modality in which "the speaker gives an undertaking or guarantees that the event will take place" (Palmer 1979:62-63):

> I intend to see that . . . , where firearms are used, the maximum penalty shall be the maximum penalty available to the law.[6]

A similar use of SHALL occurs in regulations (63):

> The 1947 act shall have effect as if this section were included in Part III thereof.[6]

The deontic use of SHALL is similar to the other degrees of deontic modality in that there is no marking for past.

If the modality is to be negative, it is expressed in verbs other than SHALL, e.g.,

> I don't promise to write that letter.

The event is negated through the use of shan't (Palmer 1979:64):

> You shan't go there tomorrow.[6]

Other possible deontic modals. Palmer considers SHOULD and OUGHT TO for inclusion as deontic modals, but he decides that they "will be treated with dynamic necessity, though they sometimes have highly deontic characteristics" (1979:69).

For various reasons Palmer includes HAD BETTER with the deontic modals. "It has no past tense forms. . . . The negative form, hadn't better, moreover, like mustn't, negates the event not the modality; it advises nonaction" (Palmer 1979:70). It would also seem to be voice neutral.

Deontic modality--questions. Questions with deontic modality are quite possible "to ask if the person addressed gives permission, lays an obligation, etc." as in (Palmer 1979:65-66):

May/can I leave now?[6]

Must I come tomorrow?[6]

Shall I reserve it tomorrow?[6]

Similar questions are used when "permission is sought as a matter of courtesy" or as an offer to act (66-7):

May I leave my telephone number?[6]

Here's our coffee. Shall I pour?[6]

Dynamic Modality

Palmer (1979:3) uses dynamic modality "to refer generally to the modality of events that are not conditioned deontically." He divides this group into two subkinds:

Neutral:	Those which indicate that an event is possible or necessary.
Subject oriented:	Those which indicate that the subject has the ability or willingness to do something.

The dynamic modals include: CAN, BE ABLE TO, MUST, HAVE (GOT) TO, DARE, SHOULD, OUGHT TO, NEED, and WILL. The subkinds will first be considered in terms of degrees and then in terms of their characteristics.

Dynamic possibility. Under dynamic possibility, Palmer considers four different uses of CAN. He then tries

to determine how these uses differ semantically from the uses of BE ABLE TO. He also includes a discussion of DARE.

The dynamic uses of CAN include neutral possibility, subject oriented possibility, implication, and occurrence with private verbs.[9] In the neutral possibility sense, CAN is used "simply to indicate that an event is possible" (Palmer 1979:71-2).

> I know the place. You can get all sorts of things here.[6]

In the subject-oriented sense, CAN indicates ability of animate subjects (Palmer 1979:73):

> He's one of the senior referees in the league, fairly strict disciplinarian, can handle games of this nature.[6]

In the case of inanimate subjects (73), "it indicates that they have the necessary qualities or 'power' to cause the event to take place."

> Religion can summate, relate, and conserve all highest ideals and values.[6]

A third dynamic possibility use of CAN discussed by Palmer (1979:73) is that in which it suggests, "by implication, that action will, or should, be taken."

> Yes, we can send you a map, if you wish.[6]

The last use of CAN which Palmer (1979:74) discusses under dynamic possibility is its use "with the so-called 'private' verbs." CAN (74) is used "with SEE and other verbs of sensation where there is little indication of ability."

> I can see the moon.[6]

It is also used with another group of verbs (75), "UNDERSTAND, REMEMBER, THINK, AFFORD, STAND, BEAR, FACE, BE BOTHERED, etc., . . . with some sense of ability or possibility."

> What you <u>can</u> remember in two weeks is the thing that matters.[6]

The differences between neutral and subject oriented dynamic modality do not account for the differences between the uses of CAN and BE ABLE TO. CAN is used in both senses as is BE ABLE TO (Palmer 1979:75-76). In this example, BE ABLE TO is used in the neutral sense:

> . . . because they are applying the disciplines already to the illumination of a particular, a practical, problem rather than a purely theoretical one, that they <u>are able</u> to become better communicators on that, on these issues.[6]

It is also found in the subject oriented sense:

> And yet you'<u>re able to</u> look at the future of it in this very objective way without making a value judgment.[6]

After much discussion and many examples, Palmer (88-9) summarizes "the conditions under which BE ABLE TO will be used rather than CAN":

(i) It alone can occur in the nonfinite forms, but will still be restricted by other considerations. . . .
(ii) It will not occur with the implicative function of CAN, or regularly with private verbs. . . .
(iii) It is much more common in writing than in speech. . . .
(iv) In present tense forms it will often indicate present actuality (but future actuality is indicated by <u>can</u>). . . .[10]
(v) In past tense forms it is obligatory if there is an indication of the actuality of a single event. . . .

(vi) It will not normally occur where a subject-oriented interpretation would not be possible (this does not mean that it will, in fact, have a subject-oriented interpretation). . . .

(vii) A distinction can be drawn between present possibility with reference to the future and future possibility. The latter requires BE ABLE TO with WILL. . . .

(viii) BE ABLE TO rarely occurs with passive forms.

The last form considered by Palmer (1979:89-90) within dynamic possibility is DARE whose meaning "is roughly 'have the courage to', in a rather weak sense since it often relates to actions that do not need much courage. . . . Semantically DARE is obviously subject-oriented."

> John <u>daren't</u> come.[6]
>
> <u>Dare</u> John come?[6]

<u>Dynamic necessity</u>. In treating dynamic necessity, Palmer discusses the indeterminacy between dynamic and deontic meanings of MUST and also considers HAVE (GOT) TO, SHOULD and OUGHT TO, and NEED.

MUST has been discussed as indicating deontic necessity. It (Palmer 1979:91) "often occurs where, in assertion, there is little or no indication of the involvement of the speaker":

> If the ratepayers should be consulted, so too <u>must</u> the council tenants.[6]

This use is considered to be neutral dynamic. Thus the crucial difference between deontic and neutral dynamic uses of MUST is whether or not the speaker is involved, but (173) "it is not always possible to distinguish between" them.

The possibility of the existence of subject oriented necessity is discussed by Palmer (1979:106), but he only found one example which could be interpreted in this manner:

> Protoplasm, the living substance of all plants, contains nitrogen and the rose tree <u>must</u> absorb this nitrogen in the form of nitrates.[6]

Very closely related to MUST are HAVE TO and HAVE GOT TO. There are certain differences between the latter two (Palmer 1979:92):

> (i) HAVE TO is more formal; HAVE GOT TO belongs to a more colloquial style and generally appears only in the spoken texts.
> (ii) HAVE GOT TO has no nonfinite forms. There is no *<u>will have got to</u>, *<u>to have got to</u>, *<u>having got to</u>. Instead the forms of HAVE TO must be used.
> (iii) HAVE GOT TO is much rarer in the past tense, and may differ in meaning from HAVE TO, in that only the latter usually implies actuality. . . .

Palmer considers three principal points in comparing and contrasting the uses of MUST and HAVE (GOT) TO (93-94):

(i) In neutral necessity, they seem interchangeable:

> I <u>must</u> have an immigrant's visa. Otherwise they're likely to kick me out you see.[6]
>
> I'<u>ve</u> really <u>got to know</u> when completion date is likely. Otherwise I might find myself on the streets.[6]

(ii) "In the present tense HAVE TO and HAVE GOT TO imply actuality, while MUST does not":

> It's a slow walk down. He'<u>s got to</u> fight his way through the crowds.[6]

(iii) The only form that can be used in situations requiring a nonfinite form is HAVE TO:

> It's too late to put him into an isolation hospital. I would have <u>had to</u> do that a few days ago.[6]

SHOULD and OUGHT TO are also discussed under dynamic necessity. They are nearly interchangeable, "even with tag questions, since there is nothing odd about" (Palmer 1979:100):

> He <u>ought to</u> come tomorrow, <u>shouldn't</u> he?[6]

Palmer (100) does suggest, however, "that SHOULD is more common than OUGHT TO."

NEED does not fit neatly into the system. It could be considered as indicating a conditional necessity.

<u>Neutral dynamic modality</u>. In neutral dynamic modality, the modality but not the event is marked for past. For possibility, both <u>could</u> and past forms of BE ABLE TO are available. With neutral necessity, past forms of HAVE (GOT) TO can be used. There is no past form of MUST.

Both the modality and the event can be marked for negation, though "normally only the modality is negated, by formally negating the modal" (Palmer 1979:78-79):

> You <u>cannot</u> treat of disease unless you know the causes.[6]

> . . . the fact that they <u>weren't able to</u> gratify it.[6]

The event could be negated by using an emphatic <u>not</u>:

> We <u>can/can't</u> nót go.[6]

For necessity, Palmer (94-95) suggests the following:

(i) The negative forms of the relevant modals with -n't or following not or in conjunction with any negative word, negate the event and express an obligation not to act:

> I think we mustn't worry too much about this. . . .

(ii) There are no forms of MUST that negate the modality (deny the obligation). Instead forms of NEED are used:

> The politics of the party machine does not and need not concern them. . . .

(iii) The negative forms of HAVE TO and HAVE GOT TO are also available, but there are two restrictions. First, although HAVE GOT TO has the negative forms has/have/hadn't got to, the negatives of HAVE TO are formed with DO--does/do/didn't have to. . . . Secondly, the negative form normally negates the modality:

> You don't have to do that.

The neutral dynamic modals are voice-neutral. Palmer (1979:87-8) found many examples of CAN in the passive but not of BE ABLE TO:

> It can easily be rubbed out.[6]

Few examples of neutral dynamic necessity were found (99):

> A lot of work has got to be done on it.[6]

Subject oriented WILL. Before considering the defining characteristics of subject oriented dynamic modality, one more degree in addition to those of possibility and necessity must be discussed, that of WILL expressing volition, power, and habit. It is not always easy to distinguish these from the other uses of WILL.

Examples of volitional WILL include (Palmer 1979:109):

> I'm seeing if Methuen will stump up any money to cover the man's time.[6]

> I said I am not competent to do it and I wouldn't have my name on the title page to do it.[6]

Power in the subject oriented sense "is little more than volition applied to inanimate objects, to indicate how such objects will characteristically behave" (Palmer 1979:110-1):

> You know that certain drugs will improve the condition.[6]

Examples of habitual activity WILL include (Palmer 1979:111):

> These are visual things. You don't need words to convey them and countries as far apart as China and Wales will use the dragon to convey basically the same concepts without any words.[6]

WOULD RATHER expresses preference in a subject oriented sense (Palmer 1979:148):

> I'd rather do the second half of the autumn term if that's all--.[6]

Subject oriented dynamic modality. As with neutral dynamic modality, in subject oriented dynamic modality, the modality can be marked for past but not the event. With possibility, either the past form could or the past forms of BE ABLE TO are available, but they do not occur in free variation. Palmer (1979:80-82) lists several conditions for the uses of could:

(i) Could may be used if there is no implication of actuality:

> I was plenty scared. In the state she was in she could actually kill.

(ii) If there is an indication not of a single action, but of successive or habitual action, could may be used, even if there is an implication that these actions took place:

> I could get up and go to the kitchen whenever I wanted to. . . .

(iii) There are no restrictions on couldn't or on could with any of the negative forms. . . .

> I ran fast, but couldn't catch the bus. . . .

(iv) Could occurs where there is a meaning of 'nothing but':

> One moment I seem to be everything to him, and then all he could think of was this child. . . .

(v) Could may also occur in seminegative or 'affective' contexts:

> He was laughing so much, he could hardly get a word out. . . .

The past form of subject oriented WILL is would (Palmer 1979:128) in a "situation, in relation to actuality, exactly like that of CAN. . . ." If there is an implication of actuality, the positive form is not used, but the negative may be:

> *I asked him, and he would come.[6]
>
> I asked him, but he wouldn't come.[6]

When WILL is used in the habitual sense (129), "actuality is implied even in positive forms":

> . . . and whenever she gardened, she would eat with dirt on her calves.[6]

The negation of subject oriented dynamic modality is a bit complicated. The modality can be negated both with CAN and WILL (Palmer 1979:78,126):

> I can't judge distance at all.[6]
>
> Even in the Sixth Form there are one or two who will not talk about sex.[6]

With CAN, the event is not negated, but with WILL it may be (127):

> I won't ask for details.[6]

The question of voice-neutrality is not simple. As far as ability goes (Palmer 1979:88), passivization does not usually occur if there is reference to a specific person:

> ?That weight can't be lifted by John.[6]
>
> That weight can't be lifted by anyone.[6]
>
> That weight can't be lifted by one man.[6]

Volitional WILL is not voice-neutral (135):

> It seems to Nebarrow that you people just won't do your homework properly.[6]

Passivization in this sentence would be quite unusual.

Dynamic modality--questions. It is quite possible to question dynamic possibility, and with dynamic necessity, "problems arise only when the negative form does not negate the modality. If it negates the modality, the same modal is used for interrogation" (Palmer 1979:96):

> Can you lift that weight?[6]

> . . . and they both have refused. <u>Need</u>
> I say more?[6]

With subject oriented WILL it is possible to question the modality (127):

> <u>Will</u> John come?[6]

<u>Other Kinds of Modality</u>

Palmer (1979:7) notes that "natural languages are notoriously untidy," and, therefore, it is not at all surprising that there are other uses of modals which do not fall neatly into his tripartite divisions. In addition to these three main kinds, he discusses futurity, conditionality and unreality, willingness, rules and regulations, rational modality, existential modality, and nonfactivity.

<u>Futurity</u>

Palmer argues that considering WILL and SHALL as markers of future tense in English is misleading. They usually carry some additional meaning as well. He suggests (Palmer 1979:111) that "BE GOING TO is more reasonably to be regarded as the form normally used for reference to the future." He (115-7) specifies "five kinds of 'modal' future with WILL":

1. Envisaged future:

> Is it ever envisaged that the College <u>will</u> hive itself off from the University?[6]

2. Hoped for, prayed for, decided future:

> We pray that God <u>will</u> look upon the hearty desires of his humble servants.[6]

3. Events within a future scene:

   Yet here we are going to find that there's going to be a National Enterprise Board which _will_ be expected to do things in Scotland.[6]

4. Description of a planned future:

   My government _will_ make it their special duty to protect the freedom of the individual under the law.[6]

5. Instructions:

   Private Jones _will_ report at 08.00 hrs.[6]

One example (112) of the rare occasion when "_shall_ has the meaning of pure futurity" is provided:

> My babe-in-arms will be fifty-nine on my eighty-ninth birthday. . . . The year two thousand and fifteen when I _shall_ be ninety.[6]

Palmer (1979:120-1) discusses various differences between WILL/SHALL and BE GOING TO. BE GOING TO is pretty much limited to spoken texsts while WILL/SHALL occur in both spoken and written. Pointing out the following contrasts (124-6), Palmer cautions the reader not to be too dogmatic:

1. BE GOING TO is used when the futurity is not conditional:

   I'm buying an awful lot of books here. It'_s going to_ cost me a fortune to get them home.[6]

2. BE GOING TO is used when no volition is suggested:

   So, _are_ you _going to_ leave a message or shall I say something?[6]

3. With WILL/SHALL, "there is little or no present activity involved":

    She'll be in soon.[6]

4. If there is any conditionality, WILL/SHALL is used:

    I'll be at home all day today except for about half an hour just after lunch.[6]

5. It is more common to find WILL/SHALL than BE GOING TO with BE ABLE TO or HAVE TO.

There is no difference between negation of futurity and negation of the event with WILL and BE GOING TO.

As for interrogation, Palmer (1979:127) finds that "the WILL of futurity is comparatively rare" while questions with BE GOING TO are apparently not uncommon.

BE GOING TO may be used to indicate future in the past in spoken text while "would is similarly used in a literary style" (Palmer 1979:130):

> I was going to say that it looked a bit like a pheasant in flight.[6]
>
> Twenty years later, Dick Whittington would be the richest man in London.[6]

Two of the uses of IS TO are discussed as indicating futurity. "The past tense forms are commonly used to refer to events that are known, in retrospect, to have been subsequent to other events. . . ." (Palmer 1979:146):

> Worse was to follow.[6]

Usually (146), "present tense forms refer to future events that are planned."

> The old group is still going strong but there'<u>s to</u> be a new girl from Norwich.[6]

Two other uses of IS TO are considered to be more modal in nature. It is "used to refer to what can be, or what can reasonably be, in both present and past" (Palmer 1979:147):

> I cannot see how this kind of overlapping <u>is to</u> be avoided.[6]

It is also used to report commands:

> He <u>is to</u> work all day.[6]

Palmer (140,148) also mentions the use of <u>were to</u> or <u>was to</u> in the <u>if</u>-clause of a conditional sentence as perhaps being a modal use expressing a rather "remote possibility."

<u>Conditionality and Unreality</u>

Sometimes interwoven with elements of futurity are conditionality and unreality. If WILL/SHALL are used for futurity, elements of conditionality, which may be manifested in various ways, are often present (Palmer 1979:113-4):

1. <u>Will</u> often occurs in the "apodisis (the main clause) of a real condition referring to the future. . . . In the protasis (the <u>if</u>-clause) a nonmodal present tense form is used."

   > If John comes, Bill <u>will</u> leave.[6]

   The events in the protasis could be past:

   > Look, if she didn't grudge you the weekend, she <u>won't</u> grudge you an alibi.[6]

2. The condition may be expressed by <u>and</u> or <u>or else</u>:

   You put it under your pillow and a fairy <u>will</u> come and give you. . . .[6]

   I don't want to stay there for ever, obviously, or else it'<u>ll</u> be terribly bad for me.[6]

3. Other conjunctions may express conditionality:

   When there is a surplus of labour, prices <u>will</u> not rise.[6]

4. The condition may be implicit:

   This <u>will</u> give us nice time to acclimatize you and have lunch before the lecture.[6]

5. It may be that the condition is understood to be an action which the reader (listener) must carry out, such as doing the asking:

   Your nursery man <u>will</u> probably spare you a few understocks.[6]

In some cases, <u>would</u> marks conditionality (Palmer 1979:139):

I <u>wouldn't</u> offer if I didn't want to do it.[6]

Interrelated with conditionality and often difficult to separate from it is unreality. There are various expressions of unreality:

1. <u>Could</u> may be used as an indication of conditionality/unreality. Palmer (1979:31) suggests that in certain examples it is the event not the modality which is conditional

or unreal. In the following examples, it is the running, not the ability, which is conditional:

> If I wanted to, I _could_ run ten miles.[6]

> If I had wanted to, I _could_ have run ten miles.[6]

2. SHOULD and OUGHT TO can express a "potential or tentative" necessity with an unreal event (Palmer 1979:101-2):

> We _ought to_ have done so much this year and we haven't done it, you know.[6]

3. In some cases WILL may express an unreal volition (Palmer 1979:134):

> Certainly doesn't want to do Reigate. He _would_ do Cuckfield, and of course, Horsham. . . .[6]

4. Unreal present and past conditionals are generally expressed with _would_, _should_, _would have_, and _should have_. There are various manifestations of the condition (Palmer 1979:139-41):

   a. It may be implicit in the linguistic context:

   > In fact, I _would have_ said that it looks as though London would be worth going through.[6]

   b. It may be implicit in a pronoun, e.g. _that_:

   > That _wouldn't_ be impossible.[6]

   c. There may be an implicit _if I were you_:

   > I _wouldn't_ be in too much of a hurry. There can't be more than about eight feet of water under your keel.[6]

d. The condition may be quite vague:

> . . . and I would certainly encourage firms to do that.[6]

Included here are expressions such as I would say, I wouldn't dream, I wouldn't know, I wouldn't mind.

5. Closely related to unreality but perhaps expressing unlikelihood is the use of should in initial position (Palmer 1979:141):

> Should it rain, the match will be cancelled.[6]

6. Unreality may be present in the use of epistemic or subject oriented dynamic modals (Palmer 1979: 141-2):

> I think I might have walked out too, from all accounts.[6]

> If he wanted to, he could pass the exam.[6]

Willingness

According to Palmer (1979:145), the decision to use BE WILLING TO is "deliberate, to express much more clearly the notion of willingness, rather than simply the 'volition' of WILL":

> The University is both anxious and willing to discharge its responsibility in this sphere.[6]

Rules and Regulations

Rules and regulations often use CAN or MAY (Palmer 1979:149):

> In the library you can take a book out and keep it for a whole year unless it is recalled.[6]

> . . . and it is subject to the final prerogative of mercy of the Home Secretary who may recommend a reprieve.[6]

Similarly, MUST may occur in reporting a rule (149):

> A spokesman for Devon County Council's Weights and Measures Department said, "Where a landlady says her place is 'two minutes from the sea,' it must not mean by jet aircraft."[6]

Rational Modality

There are certain situations in which negative or seminegative (such as with hardly) CAN express states of affairs which are unacceptable to the speaker (Palmer 1979:151):

> Come off it! You can hardly call Cynthia inscrutable.[6]

Could (151) is similarly used, but it is tentative:

> So in some degree you could say it would be taking him rather too literally.[6]

MUST (152) may also be used in this manner:

> The government must act. It must make up its mind about priorities--offices or houses, housing estates or luxury buildings.[6]

Such occurrences do not really fit into Palmer's system, and he refers to them as rational modality.

Existential Modality

CAN and MAY are both used to indicate "some" or "sometimes" (Palmer 1979:153-4):

> Roses can be mauve.[6] (some)
>
> The weather can be awful.[6] (sometimes)
>
> One of us has evidence which agrees with the earlier hypothesis of Chapman and Salton (1962) that the lamellae may arise de novo from the middle of the cell and migrate to the periphery.[6] (some)

> The process may be carried out indiscriminately by the wind or by insects which fly from flower to flower.[6] (sometimes)

It is also possible to make past time references (154):

> Yes, but she could be nasty.[6] (sometimes)
>
> Dinosaurs could be dangerous.[6] (some)

MUST (155) may be used in a similar manner to indicate "that what is said is true of all things being referred to; but at the same time it has an implication that this results from an essential characteristic":

> All scientific results must depend on a rather specialized form of history.[6]

In many cases, however, "the dividing line between an epistemic and a 'characteristic' interpretation is not very clear" (155).

Nonfactivity

There are several uses of MAY which seem to indicate nonfactivity "where a modal with a more specific meaning is not appropriate" (Palmer 1979:158-60):

1. This use sometimes appears in writing while a more informal style might use CAN:

   > Calder Idris, however, may be climbed from other points on this tour.[6]

2. The sense intended in the following example seems to be related to a "proper description":

   > We operate what might be described as a gigantic tutorial system.[6]

3. There is an idea of "conceivable" in the following example:

> They did their best, but it soon became clear that they were in a foreign country. I _might_ have been talking to them in Coptic.[6]

4. Suggestions are often made with _might_:

> You _might_ even pay a visit.[6]

5. There is an idomatic use of _might_ with _(just) as well (have)_:

> I _might_ as well have stayed at home.[6]

6. Like _would_, _might_ can indicate habitual past activity:

> In those days we _might_ go for a walk through the woods.[6]

7. It is also possible to consider here the subordinate use of MAY with a purpose clause:

> How can you keep bees? You have to have lots of land in order that they _may_ eat.[6]

8. Wishes may fall into this nonfactivity use:

> _May_ God bless you all through the coming year.[6]

9. Perhaps also to be considered here is the concessive use of MAY:

> However difficult it _may_ be. . . .[6]

A brief evaluation of the work of Joos and Ehrman has been presented, followed by a detailed presentation of Palmer's outstanding work which has been chosen as the basis for the present study.

Notes

1. The Brown University corpus consists of over a million words of written text, 500 samples of about 2000 words, collected and computerized at Brown University under the direction of W. Nelson Francis. The texts were all published in 1961 in the United States.

2. The Survey of English Usage is an extensive oral and written corpus collected at University College, London. Randolph Quirk (1980:1) describes this corpus as "a resource base not only without remote parallel elsewhere in the world for the study of English, but unparalleled (though now being imitated) for the study of other languages."

3. I have attempted to follow Palmer's notational system (1979:32) and use capital letters for lexical items, e.g. WILL, and underlining for forms, e.g. <u>will</u>, <u>would</u>.

4. Palmer uses terms from Von Wright's (1951) work on modal logic.

5. In the sentence <u>Jim may be at home</u>, the proposition is expressed in <u>Jim is at home</u> and the modality by <u>may</u>. In the sentence <u>Jim can play tennis well</u>, the event is playing tennis, and the modality is expressed by <u>can</u>.

6. The example is taken from Palmer. The modal has been underlined to facilitate readability.

7. The example which Palmer (1979:56) uses to indicate lack of voice neutrality is

John <u>may</u> want to see Mary.

(Mary <u>may</u> want to be seen by John.)

This, however, seems to be a strange passive since it is a two story sentence. I have not been able to come up with a one story sentence with an epistemic modal in which the proposition is not voice neutral.

8. <u>Would</u>, <u>should</u>, <u>could</u>, and <u>might</u> correspond to <u>will</u>, <u>shall</u>, <u>can</u> and <u>may</u>, respectively, in indirect speech.

9. Palmer (1979:74) attributes this term to Hill (1958:207, quoting Joos).

10. Palmer (1979:163) defines <u>actuality</u> as "the implication that the event did, does, or will take place."

CHAPTER III
DATA COLLECTION AND ANALYSIS METHODOLOGY

Data Collection

Data were collected from classes in which first semester graduate students could have enrolled during the 1981 fall semester at the University of Florida. Six courses were involved: two in computer sciences (C-1 and C-2), two in engineering (E-1 and E-2), and two in medicine (M-1 and M-2). One classroom lecture was recorded in each course and then transcribed thus providing the spoken data. The written data consist of selections from reading assignments corresponding to the recorded lectures.

Only classes with native-American English-speaking professors speaking what Kenyon and Knott (1953:xxxii) describe as a Northern dialect were recorded. All professors were males between forty and fifty years old with between eight and twenty-five years of teaching experience. The professors chose the class to be recorded and in each case indicated that they considered the specified class to be lecture-type.

The number of students ranged from eight to twenty-five with the exception that M-1 had eighty-five students. (Large classes seem to be common in the College of Medicine.)

In each case, one entire class was recorded. The time involved ranged from forty to sixty minutes. This information is summarized in the following table:

Table 3-1
Number of Students and Class Length

Class	Number of Students	Length of Class (minutes)
C-1	10	40
C-2	8	50
E-1	25	40
E-2	8	55
M-1	85	60
M-2	15	60

Three small cassette recorders (Realistic, Panasonic, and General Electric) with built-in microphones were situated in different places in the classroom in order to collect the data more accurately than would a single player. More sophisticated equipment was not used in an effort to avoid inhibiting the professors and/or students. Twelve Sony and six Scotch 120-minute cassettes were used. The best recording in each case was copied onto Scotch 60-minute cassetes for use in the transcription phase of the project.

The lectures were painstakingly transcribed. The professors were consulted to clarify areas which caused difficulty in transcription. The transcriptions resulted in a corpus of about 40,000 spoken words distributed as indicated in Table 3-2. (Only professors' words were counted for this study. Hesitation phenomena were not counted as words.) The transcriptions are provided in the appendices. Brief summaries of these lectures are provided below.

Once the word count of spoken data was made, an equivalent amount of written data was selected from reading assignments corresponding either to the recorded class or to the immediately preceding or immediately following class. The reading selections were chosen so that they represented entire articles, entire chapters, or entire sections of a given chapter. (It is feasible that certain modals might be more characteristic of different parts of a selection as suggested in Lackstrom 1979.) The written data amount to about 40,000 words. (Equations were not considered to be words and thus were not counted.) The words were distributed as indicated in Table 3-2. Brief summaries of the reading selections are provided below.

Table 3-2
Spoken and Written Data Base

Class	Spoken	Written	Total
C-1	5,901	5,127	11,028
C-2	6,291	5,529	11,820
E-1	3,831	4,529	8,360
E-2	7,088	6,188	13,276
M-1	8,188	8,237	16,425
M-2	8,030	9,260	17,290
Total	39,329	38,870	78,199

Lecture Summaries

C-1. The professor discusses projects which are to be carried out by the students. He then continues a discussion (begun in a previous class) about implementation of types at compile and run time in different computer languages. Explanations and examples are presented.

Questions from students are answered as they arise. Some transparencies are used during parts of the discussion, and the blackboard is used extensively. At the end of the class, the professor mentions what they will be doing in future classes.

C-2. The professor announces a lecture which will be taking place immediately after the class period. Plans for the remainder of the semester are discussed. The professor then continues a discussion of feedback related techniques. He includes a discussion of an experiment described in the textbook. (This forms part of the written data for C-2.) He then moves on to discuss microfilm technology. He uses pictures, transparencies, and actual samples during his presentation. Questions from students are answered as they arise.

E-1. The professor continues a discussion on graphical aspects of linear programming, working through examples. (These same examples are worked out in the section of the textbook which is used as the written data for E-1.) Student questions are answered as they arise. The blackboard is used extensively. In the following class, they are to deal with mathematics related to the graphical interpretation.

E-2. The professor reviews the discussion from the previous class on the indirect tensile test and moves on to discuss its relation to elastic theory and hypothetical stresses. A handout is provided for the students, and the

blackboard is used extensively. The professor uses slides when he goes on to discuss pavement systems. Discussion of this topic is to continue in the next class. Student questions are answered as they arise.

M-1. The professor begins by revising the schedule for the remainder of the semester. The class lecture is given to prepare students for laboratory work on superficial structures and muscles of the lower extremity. The students are provided with blank diagrams which they fill in during the lecture as the professor fills in similar diagrams on the blackboard. A replica of a human skeleton is also used during explanations and descriptions. Student questions are answered as they arise.

M-2. The professor continues lecturing on the neuromuscular system, specifically motor control at the spinal cord levels. He discusses two viewpoints on the organizing principles of segmental motor control. Experiments relating to each viewpoint are discussed. (One of the viewpoints is presented in the article used as the M-2 written data.) Slides are used throughout the lecture. Student questions are answered at the end of the lecture.

Reading Summaries

C-1: Blake 1977:30-8. This is a journal article describing high-performance computer systems. There is a two paragraph introduction followed by sections on process address space, procedure call, instruction frequency measurements, and stack hardware.

C-2: Salton 1975:472-93. This is a section of a chapter in a textbook. The chapter title is "Dynamic Information Processing," and the two assigned sections deal with feedback searching and document space modification. These sections consist mainly of explanations and examples.

E-1: Shamblin and Stevens 1974:243-74. This is a portion of the tenth chapter of the textbook. It includes an introduction and sections on graphical interpretation, algebraic solution, and maximization. The concepts are explained, and then sample problems are solved with the step-by-step procedures given.

E-2: Asphalt Institute 1974:46-73. The selected portions include part of the third and all of the fourth chapters. The entire manual consists basically of instructions and procedures for running an asphalt plant.

M-1: Tobin 1961:214-30. This is a portion of a human dissection laboratory manual. The particular sections analyzed provide instructions and explanations for the dissection of the following parts of the inferior extremity: the gluteal region, the flexor region of the thigh, the popliteal fossa, the posterior crural region, the anterior crural region, the dorsal region of the foot, and the lateral crural region.

M-2: Henneman 1980:718-37. This is a portion of a chapter of an anthology of medical physiology. The analyzed portion describes the concept of the motoneuron

pool and discusses experiments dealing with motoneuron size and pool organization.

Data Analysis

Once the data were collected, the number of modal forms, as defined in Palmer's study, were counted. The results are presented and discussed in Chapter IV.

The final step in the research carried out for this study was the meaning analysis. Each sentence containing a modal was considered.[1] An attempt was made to classify the meanings according to Palmer's framework as presented in Chapter II. If necessary, the modal was studied in its contextual environment beyond the sentence. It is acknowledged that this meaning analysis was the most difficult part of the research because of the very close, complicated relationships among the various meanings. The results of this analysis are presented and discussed in Chapter V.

Note

1. Sentence punctuation has been imposed on the spoken data. Someone else transcribing this material might impose it in a different manner, but this does not affect the present study.

CHAPTER IV
FORM FREQUENCY ANALYSIS

The form frequency analysis involves looking at the individual tokens which occur in the data as well as the kinds of structures in which they occur, e.g. finite or nonfinite verb phrases, active or passive, etc. The forms considered are those defined by Palmer (see Chapter II). Although he does not include _used to_, he does discuss its relationship to the system, and, therefore, it has been counted in this study.

The spoken data provide certain quirks not found in the written. For example, there are contracted modal forms in the spoken but not in the written. Thus for comparison purposes, the contractions have been counted as full forms. This, however, presents the problem of whether to consider _'ll_ as _shall_ or _will_. In keeping with what has been done in other studies (Joos 1964:162-3; Palmer 1979:112), Jespersen's conclusion that _'ll_ is from _will_ and not _shall_ is used. According to Jespersen (1954:296), while we have no example of the sound [ʃ] being dropped in weak positions, the sound [w] tends to disappear in weak syllables, cf. such words as _answer_, _Southward_, _hap'orth_, _Greenwich_. . . ." Another quirk in the dpoken data is that certain forms occur in incomplete structures, as in this example of _can_:

> So I can now, let's see, the type of that node then is, since I have an R and a D being mixed, will be what? (Appendix A:140)

The number of modals in such incomplete structures is noted in Table 4-1. Since it would be very difficult, if not impossible, to determine the meaning of the modals in such structures, they are not included in the overall calculations. There are, of course, no such occurrences in the written data.

Table 4-1
Modals in Incomplete Structures: Spoken

Modal	C-1	C-2	E-1	E-2	M-1	M-2	Total
can	6	2	2	0	4	3	17
will	1	5	2	1	11	1	21
would	0	6	0	3	10	0	19
going to	2	0	2	0	3	0	7
may	0	0	0	0	0	0	0
should	0	0	0	0	1	0	1
have to	0	2	0	0	1	0	3
might	0	3	0	0	1	0	4
could	3	0	0	0	1	0	4
must	0	0	0	0	0	0	0
able to	0	0	0	0	0	0	0
is to	0	0	0	0	0	0	0
ought	0	1	0	0	0	0	1
shall	0	0	0	0	0	0	0
used to	0	0	0	0	0	0	0
Total	12	19	6	4	32	4	77

Occurrence Analysis

A total of 1553 modals, 1099 in the spoken and 454 in the written data, in completed structures were found. No examples of dare or need used as modals were found, nor were there any examples of be willing to, would rather, had better, or be bound to. Table 4-2 lists the number of

occurences of the different modal forms. It also indicates the percent of each form for the spoken modals, for the written modals, and the total number of modals in the data.

Table 4-2
Modals in Spoken and Written Data

Modals	Spoken Tokens	Spoken Percent	Written Tokens	Written Percent	Total Tokens	Total Percent
can	228	20.76	91	10.04	319	20.54
will	218	19.83	77	16.96	295	18.99
would	211	19.19	14	3.08	225	14.48
going to	167	15.19	0	0.00	167	10.75
may	48	4.36	102	22.46	150	9.65
should	31	2.86	88	19.38	119	7.66
have to	90	8.19	1	0.22	91	5.85
might	38	3.45	20	4.40	58	3.73
could	38	3.45	17	3.74	55	3.54
must	1	0.09	35	7.70	36	2.31
able to	18	1.63	2	0.44	20	1.28
is to	8	0.72	4	0.88	12	0.77
ought to	1	0.09	2	0.44	3	0.19
shall	1	0.09	1	0.22	2	0.12
used to	1	0.09	0	0.00	1	0.06
Total	1099	99.92	454	99.96	1553	99.92

Chi-square tests were used to determine if there is a significant difference between the use of modals in the spoken and written data.[1] The x^2 values for forms occurring ten or more times (<u>can</u>, <u>will</u>, <u>would</u>, <u>going to</u>, <u>may</u>, <u>should</u>, <u>have to</u>, <u>might</u>, <u>could</u>, <u>must</u>, <u>able to</u>, <u>is to</u>) are presented in Table 4-3:

Table 4-3
Chi-Square Values for
Spoken versus Written Data

Data	x^2
All	657.895*
Computers	284.657*
C-1	162.839*
C-2	107.436*
Engineering	220.474*
E-1	75.738*
E-2	149.392*
Medicine	228.692*
M-1	126.300*
M-2	108.955*

*: Significant at the .01 level

In this table, All refers to the entire corpus. Computers, Engineering, and Medicine refer, respectively, to the C-1 plus C-2, E-1 plus E-2, and M-1 plus M-2 data. As all of the figures are significant at the .01 level, in all areas there is a statistically significant difference between the use of modals in the spoken and written data. Because of the results of the general test, individual modals were tested. The results for these tests are given in Tables 4-4 and 4-5.

Table 4-4
Tests for Individual Modals:
Spoken versus Written

Modal	All	Computers	Engineering	Medicine
can	7.671**	6.728**	0.098	6.476**
will	8.209**	6.325**	2.209	6.114**
would	13.133**	7.571**	5.842**	9.113**
going to	12.923**	6.708**	8.367**	7.211**
may	-4.409**	-4.557**	-3.753**	1.067
should	-5.225**	-0.229	-6.500**	-0.667
have to	9.330**	7.285**	5.385**	X
might	2.364	1.616	1.604	0.832
could	2.562	2.138	2.132	0.229
must	-12.671**	X	-4.359**	-3.464**
able to	3.578**	4.000**	X	X
is to	1.155	X	X	X

**: significant at .01 level
X : insufficient forms for computation
Positive numbers indicate form occurs more often in spoken data while negative numbers indicate more frequency in written data.

Table 4-5
Tests for Individual Modals:
Spoken versus Written
by Class

Modal	C-1	C-2	E-1	E-2	M-1	M-2
can	6.124**	2.874*	-1.871	2.143	4.271**	4.899**
will	5.166**	3.651**	0.309	2.524	4.628**	4.359**
would	5.308**	5.477**	2.268	5.831**	6.782**	6.091**
going to	5.292**	4.123**	6.708**	5.000**	5.745**	4.359**
may	-0.535	-4.919**	X	-3.507**	-1.279	2.837*
should	X	0.258	X	-6.274**	-2.449	2.309
have to	6.410**	3.464**	4.690**	X	X	X
might	0.577	1.606	X	1.941	X	0.000
could	1.508	X	X	3.742**	X	-1.069
must	X	X	X	-3.162	X	X
able to	3.317**	X	X	X	X	X
is to	X	X	X	X	X	X

**: significant at .01 level
* : significant at .05 level
X : insufficient forms for computation
Positive numbers indicate form occurs more often in spoken data while negative numbers indicate more frequency in written data.

As indicated in Table 4-4, there is a statistically significant difference in the use of certain modals in the spoken versus written data. Can, will, would, going to, have to, and able to are used more in the spoken data than in the written. May, should, and must are more common in the written data. We can also note statistically significant differences of modal use within the data for the three disciplines:

Computers: Can, will, would, going to, have to, and able to occur more often in the spoken while may occurs more often in the written data.

Engineering: Would, going to, and have to occur more often in the spoken while may, should, and must occur more often in the written data.

Medicine: Can, will, would, and going to occur more often in the spoken while must occurs more often in the written data.

Within the individual classes, as shown in Table 4-5, we can note the following statistically significant differences:

C-1: Can, will, would, going to, have to, and able to are all more common in the spoken data.

C-2: Can, will, would, going to, and have to are more common in the spoken data while may is more common in the written.

E-1: Going to and have to are more common in the spoken data.

E-2: Would, going to, and could are more common in the spoken data while may, should, and must are more common in the written data.

M-1: Can, will, would, and going to are more common in the spoken data.

M-2: Can, will, would, going to, and may are more common in the spoken data.

We can also look at the use of the forms in the individual sets of data. The results of frequency counts for the individual sets are given in Tables 4-6 through 4-13. In these tables, the modals are listed according to frequency of occurrence, and the percent is also given in each case. Differences and similarities in modal use can be noted between the spoken and written data for each class as well as between classes.

Structure Analysis

Finite Verb Phrases

Knowing what percent of finite verb phrases use modals will help us to determine how much emphasis they should receive in EST teaching. Because some of the modals defined by Palmer may have nonfinite forms, e.g. have to, the form occurrence figures will be revised to exclude them. There are 15 nonfinite occurrences of be able, 10 in spoken C-1 and 5 in spoken C-2. There are 29 nonfinite occurrences of have to, 22 in spoken C-1, 4 in spoken C-2,

Table 4-6
Spoken C-1

Modal	Tokens	Percent
can	78	28.36
will	48	17.45
have to	44	16.00
would	41	14.90
going to	28	10.18
able to	11	4.00
could	8	2.90
might	7	2.54
may	6	2.18
shall	1	0.36
should	1	0.36
must	1	0.36
used to	1	0.36
Total	275	99.95

Table 4-7
Written C-1

Modal	Tokens	Percent
can	18	32.72
will	9	16.36
may	8	14.54
might	5	9.09
would	5	9.09
could	3	5.45
must	3	5.45
should	3	5.45
have to	1	1.81
Total	55	99.96

Table 4-8
Spoken C-2

Modal	Tokens	Percent
would	30	20.54
can	26	17.80
will	25	17.12
going to	17	11.64
might	13	8.90
have to	12	8.21
should	8	5.47
may	6	4.10
be able	5	3.42
could	3	2.05
ought	1	0.68
Total	146	99.93

Table 4-9
Written C-2

Modal	Tokens	Percent
may	39	55.71
can	9	12.85
should	7	10.00
might	6	8.57
will	5	7.14
ought	2	2.85
is to	1	1.42
must	1	1.42
Total	70	99.96

Table 4-10
Spoken E-1

Modal	Tokens	Percent
going to	45	33.83
have to	22	16.54
will	22	16.54
can	21	15.78
would	20	15.03
could	2	1.50
may	1	0.75
Total	133	99.97

Table 4-11
Written E-1

Modal	Tokens	Percent
can	35	40.22
will	20	22.98
must	9	10.34
would	8	9.19
could	6	6.89
may	4	4.59
should	3	3.44
is to	1	1.14
might	1	1.14
Total	87	99.93

Table 4-12
Spoken E-2

Modal	Tokens	Percent
will	49	25.92
would	34	17.98
can	32	16.93
going to	25	13.22
could	14	7.40
may	10	5.29
might	10	5.29
have to	7	3.70
should	6	3.17
Total	189	98.90

Table 4-13
Written E-2

Modal	Tokens	Percent
should	55	37.67
may	33	22.60
will	27	18.49
can	17	11.64
must	10	6.84
might	3	2.05
shall	1	0.68
Total	146	99.97

Table 4-14
Spoken M-1

Modal	Tokens	Percent
will	55	29.56
would	46	24.73
going to	33	17.74
can	26	13.97
may	8	4.30
should	6	3.22
could	5	2.68
have to	3	1.61
might	3	1.61
is to	1	0.53
Total	218	99.95

Table 4-15
Written M-1

Modal	Tokens	Percent
should	18	32.14
will	16	28.57
may	14	25.00
can	3	5.35
must	3	5.35
is to	2	3.57
Total	56	99.98

Table 4-16
Spoken M-2

Modal	Tokens	Percent
can	45	26.47
could	40	23.52
going to	19	11.17
will	19	11.17
may	17	10.00
should	10	5.88
could	6	3.52
is to	5	2.94
might	5	2.94
able to	2	1.17
have to	2	1.17
Total	170	99.95

Table 4-17
Written M-2

Modal	Tokens	Percent
can	9	22.50
must	9	22.50
could	8	20.00
might	5	12.50
may	4	10.00
able	2	5.00
should	2	5.00
would	1	2.50
Total	40	100.00

1 in spoken E-1, 1 in spoken M-1, and 1 in written C-1. Figures for comparing the number and percent of finite and nonfinite verb phrases in the spoken data are presented in Table 4-18 and for the written data in 4-19.

Table 4-19
Modal versus Nonmodal Finite Verb Phrases:
Spoken Data

Class	Finite VPs	Modal VPs	Nonmodal VPs	Percent Modal
C-1	724	243	481	33.56
C-2	772	137	635	17.74
E-1	468	132	336	28.20
E-2	860	189	671	21.97
M-1	917	185	732	20.17
M-2	860	170	690	19.76
Total	4601	1056	3545	22.95

In the spoken data, the overall percent of modals in finite verb phrases is 22.95, ranging from a low in C-2 of 17.74 to a high in C-1 of 33.56.

Table 4-20
Modal versus Nonmodal Finite Verb Phrases:
Written Data

Class	Finite VPs	Modal VPs	Nonmodal VPs	Percent Modal
C-1	423	54	369	12.76
C-2	397	70	327	17.63
E-1	431	87	344	20.18
E-2	421	146	275	34.67
M-1	593	56	537	9.44
M-2	591	40	551	6.76
Total	2856	453	2403	15.86

The overall percent of modals in finite verb phrases in the written data is 15.86, ranging from a low in M-2 of 6.76 to a high of 34.67 in E-2.

In his study, Joos (1964:148) found that 16.7 percent of the finite verb phrases in the trial transcript contained modals. Before we can compare figures with Joos' study, however, we have to limit them to figures for the forms he considered. To do this, we have to remove the figures for going to, have to, able to, used to, and is to. This results in the figures shown in Table 4-21 for the spoken data and Table 4-22 for the written data.

Table 4-21
Spoken Finite Verb Phrases:
Altered for Comparison with Joos' Study

Class	Finite VPs	Modal VPs	Nonmodal VPs	Percent Modal
C-1	724	191	533	26.38
C-2	772	112	660	14.50
E-1	468	66	402	14.10
E-2	860	155	705	18.02
M-1	917	149	768	16.24
M-2	860	142	718	16.51
Total	4601	815	3786	17.71

Table 4-22
Written Finite Verb Phrases:
Altered for Comparison with Joos' Study

Class	Finite VPs	Modal VPs	Nonmodal VPs	Percent Modal
C-1	423	54	369	12.78
C-2	397	69	328	17.38
E-1	431	86	345	19.95
E-2	421	146	275	34.67
M-1	593	54	539	9.10
M-2	591	38	553	6.42
Total	2856	447	2408	15.65

The altered figures indicate that in the spoken data, 17.71 percent of the finite verb phrases contain modals with a range from 14.10 in E-1 to a high of 26.38 in C-1. The

overall percent of modal finite verb phrases is 15.65 for the written data with a range from 6.42 in M-2 to 34.67 in E-2. In comparing these figures with Joos' 16.7 percent, we can note a slightly higher percent in the spoken data (17.71) and a slightly lower percent in the written data (15.65).

Almost twice as many modals are found in the spoken data as in the written. The percentages of finite verb phrases with modals, however, are very close in both sets of data. Therefore, it may be the case that the use of more finite verb phrases, modal and nonmodal, is characteristic of spoken as opposed to written data.

It is also possible to compare statistics in the present study with those of Barber 1962. Barber looks at various measurable characteristics of modern scientific prose, including modals. His analysis is based on selections from three different American textbooks: one on engineering electronics, one on biochemistry, and one on astronomy. The data base totals approximately 23,400 words. In his study, Barber does not include <u>will</u> and <u>shall</u> as modal auxiliaries. He finds that 16 percent of the 1763 finite verb phrases contain modals (Barber 1962:26). The breakdown of modals in his study is summarized in Table 4-23 (based on Barber 1962:29):

Table 4-23
Barber's Study

Modal	Tokens	Percent
can	110	38.0
may	101	35.0
must	46	16.0
should	13	4.5
would	10	3.5
could	5	1.7
might	2	0.7
let	1	0.4
Total	288	99.8

Revisions of the spoken and written data from the present study to compare with Barber's study are provided in Tables 4-24 and 4-25, respectively:

Table 4-24
Spoken Data:
Revised to Compare with Barber's Study

Modal	Tokens	Percent
can	228	35.84
would	211	33.17
may	48	7.54
might	38	5.97
could	38	5.97
should	31	4.87
must	1	0.15
let	41	6.44
Total	636	99.95

Table 4-25
Written Data:
Revised to Compare with Barber's Study

Modal	Tokens	Percent
may	102	27.41
can	91	24.46
should	88	23.65
must	35	9.40
might	20	5.37
could	17	4.56
would	14	3.76
let	3	0.80
Total	372	99.96

It is not clear whether Barber did not include ought to or if there were no occurrences in his data. In the present study, there was 1 occurrence in the spoken and 2 in the written data. The revisions result in 13.82 percent of the spoken finite verb phrases and 13.02 percent of the written containing modals. In both cases, the percent is lower than the 16 percent found in Barber's study.

Wingard (1981:55) found modals to account for 10.21 percent of the finite verb phrases in four medical texts. The percents ranged from 7.37 to 15.87 percent. In Wingard's study the percent is lower than that found in the present study. It is interesting to note, however, that the percents for modals in the written medical data in the present study are noticeably lower than those in other areas (see Table 4-20).

Active versus Passive

Another often discussed verb phrase topic is the extent to which the passive voice is used. The figures for the present study are provided in Table 4-26.

Table 4-26
Passive versus Active Modal Verb Phrases

Class	Spoken			Written		
	Passive	Active	Percent Passive	Passive	Active	Percent Passive
C-1	20	223	8.23	22	32	40.74
C-2	5	132	3.64	42	28	60.00
E-1	0	132	0.00	50	37	57.47
E-2	2	187	1.05	78	68	53.42
M-1	6	179	3.24	54	2	96.42
M-2	11	159	6.47	17	23	42.50
Total	44	1012	4.16	263	190	58.05

The overall percent of passives for the spoken data is 4.16 percent with a range from 0.00 in E-1 to 8.23 in C-1. The overall percent of passives for the written modals is 58.05 with a range from 40.74 in C-1 to 96.42 in M-1.

Figures for comparing the active versus passive modal verb phrases are not readily available for the Joos study. Barber (1962:29) found that 58 percent of the modal verb phrases to be passive in his (written) data. Winegard (1981:55) notes 102 modal verb phrases with 66 or 64.70 percent passive. Thus, the 58.05 percent finite modal verb phrases in the passive in the present study does not seem unusual for written data.

Other Structures

As the modal forms were being counted, it was noted that they occur in a variety of structures in addition to the modal plus basic form of the verb. They occur with the progressive, in the negative, with have plus a past participle, as proforms, with two verbs such as can locate and erase, in questions, in contracted forms, and with

intervening adverbs as in <u>should carefully prepare</u>. The figures for such occurrences have been tabulated and presented in Table 4-27 for the spoken and Table 4-28 for the written data.

Table 4-27
Modals in Other Structures: Spoken Data

Structure	C-1	C-2	E-1	E-2	M-1	M-2	Totals
Progressive	5	3	6	8	5	1	28
Negative	14	9	5	11	18	13	70
<u>Have</u> plus PP	7	0	1	4	2	0	14
Proforms	2	2	4	0	2	2	12
Two verbs	11	7	2	7	11	7	45
Questions	13	9	0	3	2	3	30
Contractions	57	48	26	64	61	18	331
With adverbs	6	7	12	18	16	14	73

Table 4-28
Modals in Other Structures: Written Data

Structure	C-1	C-2	E-1	E-2	M-1	M-2	Totals
Progressive	0	0	0	1	0	0	1
Negative	0	3	7	6	2	1	19
<u>Have</u> plus PP	0	1	4	0	0	1	6
Proforms	0	0	0	0	0	1	1
Two verbs	0	0	2	6	4	5	17
Questions	0	0	1	0	0	0	1
Contractions	0	0	0	0	0	0	0
With adverbs	8	13	15	9	22	8	75

Some interesting similarities and differences can be noted in comparing the figures for spoken and written data. In the spoken data there are a large number of contractions while in the written there are none. In the spoken data, structures with intervening adverbs are about as common as negative structures while in the written data they are much more numerous than the negatives. In both

sets of data, there are a noticeable number of modals with compound verbs.

General Comments and Conclusions on Form

It must be acknowledged that the variables involved prohibit sweeping generalizations. It might be the case that the results are due to individual differences rather than being attributable to EST in general. More homogeneity might be found if, for example, each lecturer or reading selection were discussing an experiment. Nevertheless, all of the data represent lectures or reading selections with which a foreign student could have been confronted. It must also be noted that the present study is exploratory in nature.

With these reservations in mind, we can summarize the findings from the form analysis:

1. In the overall data, can, will, would, going to, have to, and able to seem to be more characteristic of spoken EST while may, should, and must seem to be more characteristic of written EST.
2. Spoken EST may have a higher percent of finite verb phrases with modals than written EST, 22.95 percent as opposed to 15.89 percent in the present study.
3. Written medical material may have fewer finite verb phrases with modals than are found in other types of EST. (It may be that the particular texts analyzed were of a factual nature.)

4. Modals in passive verb phrases are infrequent in spoken EST (only 4.16 percent) but quite common in the written EST (58.05 percent).
5. Contractions are rampant in the spoken data and nonexistent in the written data.
6. Intervening adverbs are not infrequent in either the spoken or written data. A similar statement can be made about modals with two verbs.

Note

1. All statistics for Tables 4-3, 4-4, and 4-5 have been worked out by Naomi R. Fuller, Statistics Department, University of Florida.

CHAPTER V
MEANING ANALYSIS

The nature of the modals as a class is such that the regularities are complex. The untidiness which characterizes modals is, of course, found in all systems that attempt to represent them, Palmer's included. Nevertheless, the meaning analysis carried out here on the basis of Palmer's system did yield some regularities and broad patterns.

Modals found in the data are analyzed according to the presentation of Palmer's system in Chapter II. The analysis was carried out in two steps. First utterances containing a given modal were considered and grouped according to the meaning involved. Once the groups were formed, they were then considered in terms of Palmer's kinds and degrees of modality. If various meanings appeared to be present simultaneously in the same modal occurrence, the modal was classified according to what seemed to be the predominant meaning in the context. The results of this analysis are presented in an order paralleling the framework presented in Chapter II.

Epistemic Modality

Epistemic (cf. Chapter II:20) uses of <u>may</u>, <u>cannot</u>, <u>might</u>, <u>must</u>, <u>should</u>, <u>will</u>, and <u>would</u> were found as

summarized in Table 5-1:

Table 5-1
Epistemic Uses of Modals

Modal	Spoken	Written	Total
may	20	37	57
cannot	1	3	4
might	24	12	36
must	0	6	6
should	13	8	21
will	13	25	38
would	60	2	62
Total	131	93	224

If we compare these figures with the overall figures for form occurrence (cf. Table 4-2, Chapter IV:60), we can note the following:

<u>may</u>: Almost half, 20 out of 48, of the spoken forms and a third, 37 out of 102, of the written forms are used in an epistemic sense. More than a third, 57 out of 150, of the total number of occurrences are epistemic.

<u>cannot</u>: Very few of the forms are used in an epistemic sense, only 1 out of 228 spoken and 3 out of 91 written.

<u>might</u>: About two-thirds, 24 out of 38, of the spoken forms and three-fifths, 12 out of 20, of the written forms are used in an epistemic sense. Almost two-thirds, 36 out of 58, of the total number of occurrences are epistemic.

must: The one spoken form is not epistemic. About a sixth of the written and overall forms, 6 out of 35, are used in an epistemic sense.

should: Almost half, 13 out of 31, of the spoken forms and an eleventh, 8 out of 88, of the written forms are used in an epistemic sense. About a sixth, 21 out of 119, of the total number of occurrences are epistemic.

will: Very few of the spoken forms, 13 out of 218, or written forms, 25 out of 295, are used in an epistemic sense. Only about an eighth, 38 out of 295, of the total number of occurrences are epistemic.

would: More than a fourth, 60 out of 211, of the spoken forms and a seventh, 2 out of 14, of the written forms are used in an epistemic sense. More than a fourth, 62 out of 225, of the total number of occurrences are epistemic.

If we look at the total number of modals, epistemic uses account for about an eight, 131 out of 1099, of the spoken forms and about a fifth, 93 out of 454, of the written forms. About a seventh, 224 out of 1553, of the total number of occurrences are epistemic.

Epistemic Possibility

The distribution throughout the data of modals used in the sense of epistemic possibility (cf. Chapter II:20) is summarized in Table 5-2:

Table 5-2
Epistemic Possibility

Class	may		cannot		might	
	Spoken	Written	Spoken	Written	Spoken	Written
C-1	0	1	0	0	6	2
C-2	4	22	0	0	8	5
E-1	1	0	0	1	0	0
E-2	5	12	0	0	6	3
M-1	2	0	0	2	1	0
M-2	8	2	1	0	3	2
Total	20	37	1	3	24	12

The judgments of epistemic possibility seem, in some cases, to fall into categories of predictions, conclusions, suggestions, and reasons. Often, the redundant nature of the language reinforces these categories. Examples are given below.

1. The idea of "new customers" seems to support the predictive nature of the judgment in this statement:

    New customers whose interests match those of earlier user populations <u>may</u> profit by interacting with a document collection specifically adapted to the earlier users (Salton 1975:484).

2. <u>So</u> and <u>therefore</u> often reinforce the conclusion judgments:

    So, it <u>may</u> be more than a political question. (Appendix B:181)

> Therefore, it _might_ not allocate an independent register or uh dedicate a register for that particular variable. (Appendix A:131)

The obvious nature of a conclusion, according to the speaker or writer, may be indicated by the word _obviously_:

> Obviously, when the representation of the individual clustered items changes, the centroids used in the search process _may_ no longer adequately reflect the individual cluster contents. (Salton 1975:409-1)

3. The context may contain a form of _suggest_ indicating the suggestive nature of the judgment:

> The fact that the negative strategy can help in some cases in which the positive feedback is unusable and does not on the whole exhibit a lower overall performance suggests that a selectively applied negative policy _might_ produce further improvements in overall performance. (Salton 1975:477)

4. The context may contain a form of _reason_ indicating that the judgment provides possible reasons:

> Other reasons may be that--that there _may_ be a tumor somewhere upstream, so to speak, so that uh the blood is working against the gradient. (Appendix E: 239)

There is one example of a judgment made about a proposition in the past:

> You _might_ have heard of Reclamite, and it's supposed to rejuvenate the pavement somewhat and seal it off. (Appendix D:224)

We do find examples of the possibility of a negative proposition and the negation of the modality with can't:

> You may or may not remember that the formula for the net resistance of this circuit, of resistors in parallel, is one over R total equals the sum of the reciprocals of all the individuals. (Appendix F:274)
>
> So, again, it looks as though input resistance can't be the only determinate of rheobase, or they should all be covering the same uh range of values. (Appendix F:295)

The data also provide examples of epistemic possibility in embedded questions, such as:

> The question arises whether or not the vector modification technique might not be extended to the document vectors themselves in the hope of creating a more useful set of document identifications. (Salton 1975:483-4)

Also of interest are examples of the modality and the proposition occurring in separate clauses as in:

> So, it may be that the S's, once they start to fire, are sort of self-sustaining. (Appendix F:299)

The epistemic possibility judgments, in some cases, may be quite closely linked to the idea of conditionality as when the judgment indicates possible results under certain circumstances:

> On the other hand, if allowed to become too fine, it may lack density and fail to produce the desired surface texture. (Asphalt Institute 1974:60)

Epistemic Necessity

The distribution throughout the data of modals used in the sense of epistemic necessity (cf. Chapter II:22) is summarized in Table 5-3:

Table 5-3
Epistemic Necessity

Class	must		should	
	Spoken	Written	Spoken	Written
C-1	0	0	0	1
C-2	0	0	1	3
E-1	0	0	0	1
E-2	0	0	1	1
M-1	0	0	2	0
M-2	0	6	9	2
Total	0	6	13	8

The six examples of must expressing epistemic necessity are all found in written M-2. There are often indications in the context that a conclusion is being made as in this example:

> These observations indicated that orderly recruitment of motoneurons must depend on differences in the excitabilities of the motoneurons themselves or on some systematic difference in the input from stretch receptors, resulting in more effective stimulation of small cells. (Henneman 1980:722)

Some of the judgments with should fall into categories of predictions and conclusions as indicated, respectively, in the following examples:

> Uh I think the--during dead week, I will have project reports, and I think we should be able to do all of the project reports on two days, on Monday and Wednesday and Wednesday of dead week. (Appendix B:154)

> Since this has twice the surface area of that, its RN should be a half. (Appendix F:276)

With modals used in the sense of epistemic necessity, as was the case with epistemic possibility, we tend to find words such as since, so, and therefore in the context:

> And since this has twice the surface area of that, its surface area should be half of that and a quarter of that. (Appendix F:276)

> So, if we have the same number of boutons, and they are--they all are equally efficacious, that is, they all inject the same amount of synaptic current, and a lot of other assumptions, uh we should have an inverse relationship between the size of cell and the amplitude of the post synaptic potential developed. (Appendix F:277)

> They should, therefore, be clear, complete and accurate. (Asphalt Institute 1974:70)

The data do provide examples of judgments made about propositions in the past as in:

> The use of electrical stimulation with widely spaced electrodes must have resulted in simultaneous discharges from several pools of motoneurons. (Henneman 1980:722)

None of the examples of must being used in the sense of epistemic necessity are negative. In the examples of negation with should, the proposition is negative as in:

> Yeah, that was somewhat--femoral canal--shouldn't've slipped that in on you there. (Appendix E:257)

The data also provide examples of epistemic necessity in embedded questions, such as:

> The question arises whether the space modification process should be performed using the original user query vectors as a modification criterion or whether any of the query formulations might be usable for this purpose. (Salton 1975:489)

There is also a main clause question with epistemic necessity:

> Uh that, however, raises the question which we take up here, why should small motoneurons be recruited first? (Appendix F:272-3)

We also find an example of the necessity modality and proposition occurring in separate clauses as in:

> If CFL is very precisely and linearly related to cell size, it must be concluded that the distribution of input to the pool and any other factors that contribute to the relationship are also size dependent. (Henneman 1980:728)

As with the epistemic possibility judgments, in some cases the epistemic necessity judgments may be closely linked to conditionality in that they indicate judgments based on certain circumstances:

> If I was to go out and put a wheel load on here, measure the deflection basin, measure strain from the surface or whatever, all of those measured values should correspond to the computer predicted value using multilayer elastic theory. (Appendix D:216)

Epistemic Reasonability or Confidence

The distribution through the data of modals used in the sense of epistemic reasonability or confidence (cf. Chapter II:24) is summarized in Table 5-4:

Table 5-4
Epistemic Reasonability

Class	will		would	
	Spoken	Written	Spoken	Written
C-1	0	3	5	2
C-2	0	1	4	0
E-1	3	4	6	0
E-2	8	6	9	0
M-1	0	11	23	0
M-2	2	0	13	0
Total	13	25	60	2

In these data, when will is used in the epistemic sense, it is often difficult to distinguish between meanings

of the utterance with and without will. An especially good example of this difficulty is this compound utterance:

> So, x-two will be twelve, and x-one is minus twenty, which is back here. (Appendix C:193)

The judgments with will tend to be conclusions, often having so, thus, or obviously in the context:

> So it will be right about here, down to here, and put in this line, and again our solution has to be on the underside because it is less than or equal to these values. (Appendix C:185)

> Thus the optimal number of top-of-stack registers will minimize the number of pushes and pulls. (Blake 1977:37)

> Obviously, the new query vector will appear more similar to the relevant document set (and hence may retrieve more relevant items in the future) than the original and less similar to nonrelevant. (Salton 1975:473)

The epistemic uses of would tend to be conclusions (frequently having so, of course, then, or therefore in the context), predictions, and results of specified conditions:

> So the floor of it is adductor longus, and then the medial wall uh would be one of the vastus muscles, the vastus medialis, and that comes around like this. (Appendix E:256)

> So, in this kind of situation, then we would predict that there would be a size principle. (Appendix F:277)

> If this was a fairly brittle material with very little creep, then even though we have a slight slope here, the response that we measure would probably be the true elastic strain. (Appendix D:203)

There are examples in the data of epistemic confidence with a negative proposition as in:

> And uh that number at this point won't have any meaning to you, but. . . . (Appendix F:287)

There is one example of a question with epistemic reasonability:

> So, what would we do with it? (Appendix B:163)

Deontic Modality

Deontic (cf. Chapter II:25) uses of can, might, could, shall, ought to, and should were found as summarized in Table 5-5:

Table 5-5
Deontic Uses of Modals

Modal	Spoken	Written	Total
can	6	0	6
could	3	0	3
might	4	0	4
shall	1	1	2
ought to	1	0	1
should	3	1	4
Total	18	2	20

Very few examples of deontic modality were found in the data for this study. This seems reasonable since in a lecture situation or in the types of reading assignments involved, occasions for the use of permission, obligation, statements of undertakings, promises, and threats would be rare. Referring back to Table 4-2 (Chapter IV:60), we can note, however, that deontic modality accounts for all

occurrences of shall in the data and for the only occurrence of ought to in the spoken data.

Deontic Possibility

The distribution throughout the data of modals used in the sense of deontic possibility (cf. Chapter II: 25) is summarized in Table 5-6:

Table 5-6
Deontic Possibility

Class	can		could		might	
	Spoken	Written	Spoken	Written	Spoken	Written
C-1	3	0	1	0	1	0
C-2	1	0	0	0	3	0
E-1	0	0	0	0	0	0
E-2	0	0	0	0	0	0
M-1	1	0	2	0	0	0
M-2	1	0	0	0	0	0
Total	6	0	3	0	4	0

The only examples of deontic possibility occur in the spoken data with can, could, and might. Four of the six occurrences with can could almost be considered as dynamic possibility except that a person of higher authority is speaking to one(s) of lesser authority, e.g.,

> You can uh get some--one of the secretaries up in the office to give you four Acco press folders. . . . (Appendix A:130)

One of the occurrences of can which is considered deontic has a humorous tone in that the lecturer seems to be giving himself permission:

> As uh far as what--I can always look on the skeleton. (Appendix E:262)

There is one occurrence of <u>can</u> in a question. In this case, the difference in status between the speaker and the addressee almost makes the request a command:

> <u>Can</u> I have the projector on, please? (Appendix F:267)

One of the deontic occurrences of <u>could</u> is in a question:

> <u>Could</u> we organize something to allow those papers to circulate so that people can get a chance to copy them, have a chance to look at them? (Appendix A:128)

The other two occurrences of deontic <u>could</u> are found together. The intonation of the first part of the utterance indicates that it is a request. The tag question seems to be added in order to give the addressee time to compose his response:

> Uh maybe Dr. Lawless <u>could</u> tell us more about the vein stripping business, uh <u>could you</u>? (Appendix E:242)

The occurrences of <u>might</u> which are considered deontic seem to be extremely polite ways of giving commands. In each case, someone of higher authority, the lecturer, is speaking to people of lesser authority, students, as in:

> You might want to read it over. . . . (Appendix B:163)

<u>Deontic Necessity</u>

No examples of <u>must</u> in the data were considered to express deontic necessity.

Deontic Use of SHALL

The two occurrences of shall in these data are considered to be deontic (cf. Chapter II:28). The first, from spoken C-1, is in a question:

> Shall I try that assignment to an integer variable? (Appendix A:142)

The second is from written data, E-2:

> The samples prepared for tests shall be obtained from the field sample by quartering or other suitable means to insure a representative portion. (Asphalt Institute 1974:65)

Other Possible Deontic Modals

There are several occurrences of should and ought to which seem to be deontic (cf. Chapter II:28) in that they are placing an obligation. One is from written data, E-1:

> The reader should expand a simple case expressed by this notation to verify this method of notation. (Shamblin and Stevens 1974:246)

The others, one ought to and three should, are from spoken data:

> And, as I say, I think you ought to read it over and look at it a little more carefully, and uh I'll describe it now. (Appendix B:163)

> Really should attend. (Appendix B:153)

> Shouldn't ask me that 'cause I always have something to change. (Appendix B:155)

> Uh should I go with uh maybe a different color? (Appendix E:236)

Dynamic Modality

Dynamic (cf. Chapter II:29) uses of _can_, _could_, _able to_, _must_, _have to_, _ought to_, _should_, _will_, and _would_ were found as summarized in Table 5-7:

Table 5-7
Dynamic Uses of Modals

Modal	Spoken	Written	Total
can	212	85	297
could	5	8	13
able to	17	2	19
must	1	24	25
have to	90	1	91
ought to	0	2	2
should	13	5	18
will	62	16	78
would	6	1	7
Total	406	144	550

If we compare these figures with the overall figures for form occurrence (cf. Table 4-2, Chapter IV:60), we can note the following:

can: Almost all, 212 out of 228, of the spoken forms as well as written, 85 out of 91, are used in a dynamic sense. About seven-eighths, 297 out of 319, of the total number of occurrences are dynamic.

could: About a seventh, 5 out of 38, of the spoken forms and almost half, 8 out of 17, of the written forms are used in a dynamic sense. About a fourth, 13 out of

55, of the total number of occurrences are dynamic.

<u>able to</u>: All but one of the spoken and all of the written forms are used in a dynamic sense.

<u>must</u>: The only occurrence of a spoken form and about two-thirds, 24 out of 35, of the written forms are used in a dynamic sense. More than two-thirds, 25 out of 36, of the total number of occurrences are dynamic.

<u>have to</u>: All of the spoken and written forms are used in a dynamic sense.

<u>ought to</u>: The one occurring form in the spoken data is not used in a dynamic sense, but the only two occurring forms in the written are.

<u>should</u>: Almost half, 13 out of 31, of the spoken forms but very few, 5 out of 88, of the written forms are used in a dynamic sense. About a sixth, 18 out of 119, of the total number of occurrences are dynamic.

<u>will</u>: More than a fourth, 62 out of 218, of the spoken forms and about a fifth, 16 out of 77, of the written forms are used in a dynamic sense. About a fourth,

77 out of 295, of the total number of occurrences are dynamic.

would: Very few forms, 6 out of 211 spoken and 1 out of 14 written, are used in a dynamic sense.

The dynamic uses of modals account for about a third, 406 out of 1099, of the spoken forms and a third, 144 out of 454, of the written forms.

Dynamic Possibility

The distribution throughout the data of modals used in the sense of dynamic possibility (cf. Chapter II: 29) is summarized in Table 5-8:

Table 5-8
Dynamic Possibility

Neutral

Class	can		could		able to	
	Spoken	Written	Spoken	Written	Spoken	Written
C-1	64	12	0	0	6	0
C-2	21	8	0	0	5	0
E-1	11	32	0	0	0	0
E-2	25	12	3	0	0	0
M-1	11	1	0	0	0	0
M-2	23	6	1	6	0	0
Total	155	71	4	6	11	0

Subject Oriented

Class	can		could		able to	
	Spoken	Written	Spoken	Written	Spoken	Written
C-1	10	6	0	0	4	0
C-2	3	1	0	0	0	0
E-1	4	2	0	0	0	0
E-2	2	3	0	0	0	0
M-1	10	0	0	0	0	0
M-2	14	2	1	2	2	2
Total	43	14	1	2	6	2

Not tabulated are 14 occurrences of spoken can, 2 used in the implication sense (cf. Chapter II:30) and 12 used with private verbs (cf. Chapter II:30).

Most, 155 spoken and 71 written, of the dynamic uses of can are neutral (cf. Chapter II:30). The subject with this use in the spoken data is usually an impersonal or nonspecific subject pronoun, I, we, you, or one:

> I can clear those things with no problem. (Appendix A:144)

> We can plot the line through this point. (Appendix C:194)

> Uh uh you can really save a lot of money by generating microfilm. (Appendix B:179)

> Uh what one can do is to inject a current of one nanoamp, ten to the minus uh ninth amps, and use a prolonged uh square wave. (Appendix F:286)

Generally in the written data a passive structure is used as in:

> This basic structure can be extended easily. (Blake 1977:31)

A very specific subject is present in the cases where can is used in the subject oriented sense (cf. Chapter II:30):

> So it has to be reinitialized every time it's used because the compiler can recognize the fact that it's a low usability-- low utilization variable. (Appendix A:131)

All but one of the instances of able to found in the data are considered to indicate dynamic possibility. About three-fifths, 11 out of 19, of the occurrences are classified as neutral, e.g.,

> So, I'll be <u>able to</u> make a transition. (Appendix A:146)

All of these neutral uses are in nonfinite forms. The other two-fifths, 8 out of 20, of the occurrences are subject oriented, e.g.,

> All nine subjects were <u>able</u>, without difficulty, <u>to</u> isolate a single motor unit and to control its rate of firing from most recording sites. (Henneman 1980:736)

According to Palmer (cf. Chapter II:31), BE ABLE TO is more likely to occur in written than in spoken data. The data of the present study do not support his statement as 18 out of the 20 occurrences are found in the spoken data and only 2 in the written.

<u>Dynamic Necessity</u>

The distribution throughout the data of modals used in the sense of dynamic necessity (cf. Chapter II:32) is summarized in Table 5-9 (<u>S</u> refers to spoken and <u>W</u> to written data):

Table 5-9
Dynamic Necessity

<u>Neutral</u>

Class	must		have to		should		ought to	
	S	W	S	W	S	W	S	W
C-1	0	3	44	1	0	1	0	0
C-2	0	1	12	0	4	1	0	2
E-1	0	8	22	0	0	0	0	0
E-2	0	5	7	0	5	3	0	0
M-1	0	3	3	0	3	0	0	0
M-2	0	3	2	0	0	0	0	0
Total	0	23	90	1	12	5	0	2

Not tabulated are 2 instances of subject oriented must, 1 spoken and 1 written, and 1 of subject oriented should, spoken.

Most of the dynamic uses of must (23 out of 25) occur in the written data and are used in a neutral dynamic sense. They tend to occur either with the verb BE (6 instances) or in a passive structure (14 instances), e.g.,

> At least two of the variables must be equal to zero for the unique solution to exist. (Shamblin and Stevens 1974:252)

> Its proximal portion is covered by these muscles, which must be separated to expose it. (Tobin 1961:226)

There are two occurrences where must might be considered as being used in a subject oriented sense, one spoken and one written:

> All you really want to convey to the compiler when it's compiling the subroutine--you want to tell it that it's an array so that now the compiler knows that when it generates references to this thing, it must resolve the subscript. (Appendix A:138)

> In effect, then, management must assign the fixed resources (manufacturing time of each department) so as to optimize some object (maximize profit) and still satisfy some other defined conditions (not exceeding the departmental capacities for work). (Shamblin and Stevens 1974:243)

All the occurrences of HAVE (GOT) TO are used in a neutral sense. Only one occurrence is in the written data:

> The renamer thus prevents having to move the operands to specific registers prior to execution of microprogram. (Blake 1977:37)

There are only 4 instances of HAVE GOT TO, all in the spoken data and all in the present tense. In one of the instances, the have has been deleted:

> But you got to be very careful by the time that you get to the top that you don't overdo it. (Appendix D:222)

In their dynamic uses, should and ought to are nearly interchangeable. These data support Palmer's statement that should is more common than ought to. The neutral sense tends to occur either in a passive structure, 5 out of 19 occurrences, or with an impersonal or nonspecific subject pronoun, 9 out of 19 instances, such as I, you, we, it, one, e.g.,

> In other words the evaluation of each feedback iteration ought to be based on a constant amount of user effort. . . . (Salton 1975:482)

> . . . but no information is provided on where one should transfer instead. (Salton 1975:478)

There is one instance of should which seems to be subject oriented:

> I should introduce our visitor. (Appendix B:153)

There are no occurrences of either should have or ought to have.

Neutral Dynamic Modality

With neutral dynamic possibility (cf. Chaper II:34), could is used to mark past modality, e.g.,

> At the peak of PTP, all the MG and LG-S motoneurons were evidently discharged reflexly, as nearly as could be determined with this technique. (Henneman 1980:725)

None of the instances of neutral BE ABLE TO are in the past. Past forms of HAVE TO are used to mark past neutral necessity, e.g.,

> So he's putting down an asphalt concrete base that went up to as thick as about eighteen inches, I believe, and the fact that it was eighteen inches--they _had to_ run a bulldozer over it to compact initially, and then they ran their uh compacting equipment. (Appendix D:218)

There are examples of negation of neutral dynamic possibility with _can_, _could_, and _able to_:

> You _can't_ AND two integer variables. (Appendix A:133)

> Now, before that, you _couldn't_ convince anyone. (Appendix D:218)

> You just would not be _able to_ do that in a language that forces typing. (Appendix A:133)

For neutral dynamic necessity, there are no examples of negation with MUST, but there are several with HAVE TO, e.g.,

> That does not _have_ to be discussed in a Pascal manual because in Pascal the implementation is hidden from vision. (Appendix A:134)

Subject Oriented WILL

The distribution throughout the data of subject oriented WILL (cf. Chapter II:35) is summarized in Table 5-10:

Table 5-10
Subject Oriented WILL

Class	will		would	
	Spoken	Written	Spoken	Written
C-1	11	4	0	1
C-2	9	2	1	0
E-1	4	3	0	0
E-2	17	7	1	0
M-1	19	0	0	0
M-2	2	0	4	0
Total	62	16	6	1

For the most part, the forms in these data which are considered subject oriented generally indicate characteristic behavior, e.g.,

> Mixes designed with a minimum of fine aggregate normally <u>will</u> have a much richer appearance than the denser graded types, yet may be properly proportioned. (Asphalt Institute 1974:57)

There is one written example which seems to express power:

> There should be a lockout button, or switch, located a short distance from the plant, which <u>will</u> stop all plant operations in the event of an emergency. (Asphalt Institute 1974:57)

In the spoken data, there are four instances of <u>will</u> expressing volition as in:

> Uh and as far as uh me running it, uh I will--tell you what, I'll--I'<u>ll</u> go ahead and do this. (Appendix B:154)

And there is one spoken example which indicates habitual activity:

> I would say that this is probably the most accepted terminology, although some people <u>will</u> call it a diametral test. (Appendix D:198)

Subject Oriented Dynamic Modality

There are 6 instances of subject oriented dynamic modality (cf. Chapter II:36) which are marked for past, 3 with could and 3 with was/were able to, e.g.,

> None of the three subjects could on demand activate either motor unit at will or alternate their activity in a facile manner. (Henneman 1980:737)

> All nine subjects were able, without difficulty, to isolate a single motor unit and to control its rate of firing from most recording sites. (Henneman 1980:736)

There are 7 instances of would marking past subject oriented dynamic modality, e.g.,

> He would activate the axon by one manner or another. (Appendix F:280)

There are examples of negation with CAN and BE ABLE TO when used to indicate subject oriented possibility, e.g.,

> I obviously can't top either--either one of of those announcements. (Appendix E:229)

> But what happens is that with these very uh powerful units that are unable to sustain this contraction, and so the. . . . (Appendix F:281)

There are no examples of negation with subject oriented necessity modals, but there are examples with WILL, e.g.,

> But because IBM wouldn't do them, why, they just never did them. (Appendix B:180)

Passive constructions with subject oriented modals are quite rare. Only 5 occurrences in the 156 modals used in this sense are passive, e.g.,

> Uh the FF's uh are less than half numerically, but of the total power that <u>can</u> be developed by the muscle, they contribute around seventy-five percent. (Appendix F:285)

Futurity

Future uses of <u>going to</u>, <u>will</u>, <u>would</u>, and <u>is to</u> were found as summarized in Table 5-11 (<u>S</u> refers to spoken and <u>W</u> to written data):

Table 5-11
Future Uses of Modals

Class	going to		will		would		is to	
	S	W	S	W	S	W	S	W
C-1	28	0	24	0	0	0	0	0
C-2	17	0	15	1	0	0	0	0
E-1	45	0	6	13	0	0	0	0
E-2	25	0	7	3	0	0	0	0
M-1	33	0	23	5	1	0	0	2
M-2	19	0	14	0	0	0	0	0
Total	167	0	89	22	1	0	0	2

If we compare these figures with the overall figures for form occurrence (cf. Table 4-2, Chapter IV:60), we can note the following:

<u>going to</u>: All of the forms indicate futurity, and all occur in spoken data.

<u>will</u>: Almost half, 89 out of 218, of the spoken forms and two-sevenths, 22 out of 77, of the written forms indicate futurity. More than a third, 111 out of 295, of the total number of occurrences indicate futurity.

<u>would</u>: Only one, out of 211, of the spoken forms and none of the written forms is used to indicate futurity.

<u>is to</u>: None of the 8 spoken forms and half, 2 out of 4, of the written forms are used to indicate futurity. A sixth, 2 out of 12, of the overall occurrences are used to indicate futurity.

If we look at the total number of modals, future uses account for about a fourth, 257 out of 1099, of the spoken forms and about a twentieth, 24 out of 454, of the written forms. About a fifth, 281 out of 1553, of the total number of occurrences are future.

There are various ways that the context indicates that WILL is being used to indicate futurity. Very common is the use of time adverbs such as <u>later</u>, <u>at some point</u>, <u>then</u>, <u>next week</u>, <u>at that time</u>, etc., e.g.,

> The remaining branches <u>will</u> be seen later to supply the soleus and popliteus muscles. (Tobin 1961:220)

There are a number of instances when WILL is used to indicate events in a future scene, e.g.,

> What we're going to find is that we'<u>ll</u> go along like this. (Appendix D:201)

There are also examples of hoped for and planned futures, e.g.,

> I hope you <u>will</u> come to the lecture. (Appendix B:181)

> As *will* be shown, the simplex method of solution is simply a combination of matrix algebra with some basic rules to guide the computation to an optimal answer without exceeding any restrictions. (Shamblin and Stevens 1974:256)

Palmer suggests that BE ABLE TO and HAVE TO are more likely to occur with WILL than with GOING TO (cf. Chapter II:41), but in these data there are 6 such occurrences with WILL and 5 with GOING TO. It is interesting to note that all 11 cases occur in spoken C-1 data.

There is only one question involving futurity, with *will*:

> And what *will* we want to do here? (Appendix B:163)

There are no examples indicating future in the past with *going to*, but there is one with *would*:

> Uh since the uh schedule that I've uh kind of figured out uh is different than is in your syllabus, I thought I'*d* go ahead and--and list it there. (Appendix E:229)

There are a couple of examples of IS TO indicating futurity, both in the written M-1 data:

> The deeper structures *are* now *to be* displayed on the dorsum of the foot. (Tobin 1961:228)

> The lateral crural region *is* next *to* be examined. (Tobin 1961:229)

The other uses of IS TO will be discussed at this point although they veer away from futurity. Two occurrences seem to indicate purpose, a use not discussed by Palmer, e.g.,

> It'*s* just *to* represent the inguinal ligament. (Appendix E:258)

There are eight instances of IS TO occuring in the protasis of a conditional sentence. The possibility does not seem to be particularly remote, which is the way Palmer describes this use (cf. Chapter II:42), e.g.,

> If we were to evaluate the base force, we might use, for instance, the resilient uh modulus test for granular materials over the subgrades so that we could actually do this in the laboratory. (Appendix D:216)

Conditionality and Unreality

Conditional/unreal uses of will, would, could, should, might, and able to were found as summarized in Table 5-12:

Table 5-12
Conditional/Unreal Uses of Modals

Modal	Spoken	Written	Total
will	23	12	35
would	125	11	136
could	27	9	36
should	2	2	4
might	2	2	4
able to	1	0	1
Total	180	36	216

If we compare these figures with the overall figures for form occurrence (cf. Table 4-2, Chapter IV:60), we can note the following:

will: About a tenth, 23 out of 218, of the spoken forms and a sixth, 12 out of 77, of the written forms are used in a conditional/unreal context. About a tenth, 35 out of 295, of the total number of occurrences are conditional/unreal.

<u>would</u>: More than half, 125 out of 211, and almost all, 11 out of 14, of the written forms are used in a conditional/unreal context. More than half, 136 out of 225, of the total number of occurrences are conditional/unreal.

<u>could</u>: About three-fourths, 27 out of 38, of the spoken forms and half, 9 out of 17, of the written forms are used in a conditional/unreal context. about two-thirds, 36 out of 55, of the total number of occurrences are conditional/ unreal.

<u>should</u>: Very few, 2 out of 31, of the spoken and very few, 2 out of 88, of the written forms are used in a conditional/unreal sense.

<u>might</u>: Very few, 2 out of 38, of the spoken and very few, 2 out of 20, of the written forms are used in a conditional/unreal sense.

<u>able to</u>: Only 1 out of 18 spoken forms and none of the written forms are used in a conditional/unreal sense.

If we look at the total number of modals, conditional/unreal uses account for about a sixth, 180 out

of 1099, of the spoken forms and about a thirteenth, 36 out of 454, of the written forms. Approximately a seventh of the total number of forms, 216 out of 1553, are used in a conditional/unreal sense.

Conditionality and unreality are closely interwoven with futurity as well as with the other kinds of modality. For instance, there were certain epistemic modals expressing judgments about results under certain circumstances. The uses of <u>might</u> considered here as expressing conditionality/unreality should, perhaps, be considered as expressing tentative judgments of possibility under certain conditions, e.g.,

> If the profit per unit was known, this <u>might</u> be done to maximize profit. (Shamblin and Stevens 1974:243)

The context indicates in a variety of ways that a conditional/unreal situation is involved. There are numerous instances of <u>if-then</u> type structures, e.g.,

> If we have a mixed-mode expression, and it involves integers, reals, doubles, and complex variables, we'<u>ll</u> rank them and say that an integer variable is lower priority than a real. . . . (Appendix A:139-40)

Sometimes the condition is expressed by a prepositional phrase:

> In Pascal, you <u>would</u> have to use some other function. (Appendix A:135)

The condition may be vague or an unstated "if I were you" as in:

> I <u>wouldn't</u> worry about this. (Appendix E:262)

There is one instance of <u>should</u> expressing unlikelihood:

> <u>Should</u> S encounter Z, a trap to the operating system invokes a routine which expands the stack and then resumes execution. (Blake 1977:31)

<u>Willingness</u>

There were no occurrences of BE WILLING TO found in these data.

<u>Rules and Regulations</u>

There were 9 instances of <u>may</u> in the written E-2 data which are considered as expressing rules or regulations, e.g.,

> It <u>may</u> represent a day's production, a specified number of truckloads, a specified time period during production. (Asphalt Institute 1974:65)

<u>Rational Modality</u>

Three instances of <u>can</u>, 2 spoken and 1 written, are classified as indicating rational modality, e.g.,

> You <u>can</u> hardly say 'size principle' without saying 'Henneman'. (Appendix F:272)

There are also three instances of <u>could</u>, all spoken, used in a similar manner, e.g.,

> I think that you <u>could</u> probably use the point three five with reasonable confidence. (Appendix B:214)

<u>Existential Modality</u>

Existential uses of <u>may</u>, <u>might</u>, and <u>can</u> were found as summarized in Table 5-13:

Table 5-13
Existential Uses of Modals

Class	may Spoken	may Written	might Spoken	might Written	can Spoken	can Written
C-1	4	0	0	0	0	0
C-2	2	1	0	0	0	0
E-1	0	0	0	0	0	0
E-2	2	0	1	0	2	0
M-1	4	1	0	0	1	0
M-2	7	0	0	2	0	0
Total	19	2	1	2	3	0

With the exception of _may_ in the spoken data, there are very few instances of existential modality. This use accounts for almost half, 19 out of 48, of the spoken instances of _may_. The word _sometimes_, in some cases, occurs in the context:

> They do that here in Gainesville periodically, and sometimes it works pretty nicely, and then again, they _may_ end up with a mess. (Appendix D:224)

> Sometimes you _might_ have a two-bin separation. (Appendix D:226)

Nonfactivity

The distribution throughout the data of _may_ and _might_ used in the sense of nonfactivity (cf. Chapter II:47) is summarized in Table 5-14:

Table 5-14
Nonfactivity

Class	may Spoken	may Written	might Spoken	might Written
C-1	0	7	0	0
C-2	0	14	1	0
E-1	0	4	0	0
E-2	1	11	1	0
M-1	2	7	0	0
M-2	1	2	0	0
Total	4	45	2	0

This use of <u>may</u> accounts for almost half, 45 out of 102, of the written occurrences and about a third, 49 out of 150, of the total number of occurrences in the data (cf. Table 4-2 Chapter II:60). Most of the examples appear in the written data and would probably be <u>can</u> in a more informal style, e.g.,

> Recently, however, it has been found that there <u>may</u> be two or more types of alpha motoneurons differing in properties that are independent of size. (Henneman 1980:718)

One of the instances of <u>might</u> is used in a suggestion, and the other indicates habitual past activity:

> Uh now you <u>might</u> look at it kind of this way, that uh the--it would uh--it would uh uh make some uh--uh I mean, you know, there may be a query for which this would be a relevant document. (Appendix B:162)

> In some of the older systems, we <u>might</u> have added another layer. (Appendix D:219)

<u>Other Uses of Modals</u>

There are some uses of modals which do not coincide with those discussed by Palmer, though they are closely related.

One such use is the occurrence of <u>should</u> and <u>must</u> in written data to give instructions, e.g.,

> There <u>should</u> be a summary of the results of all tests performed during the day and a tabulation of the amounts of material received and used. (Asphalt Institute 1974:70)

> The mixture <u>must</u> fall into the job-mix tolerance and quality requirements set by the specifications. (Asphalt Institute 1974:63)

The 72 instances of should used in this manner are distributed as follows: 2 in C-2, 1 in E-1, 51 in E-2, and 18 in M-1. The 5 instances of must are all in E-2. Most of the occurrences are in the manuals, E-2 and M-1. Perhaps Palmer would include these as rules and regulations, or they might be considered almost deontic.

There are several uses of WILL which do not seem to fit in well with the previously mentioned classifications. One is the use of WILL in the spoken data to describe an action as it takes place, e.g.,

> I think I'll put two raised dots. (Appendix A:147)
>
> I'll draw in this little distribution right here. (Appendix D:208)

Eighteen such uses were noted, distributed in the following manner: 6 in C-1, 1 in E-1, 5 in E-2, 5 in M-1, and 1 in M-2. There is one occurrence in a structure which almost seems performative:

> Now I will simply state that when we get into more than two dimensions, these same concepts apply. (Appendix C:192)

Some instances of will and would are used in almost a factual sense with little indication of a judgment being involved:

> That will make this a double node. (Appendix A:141)
>
> Remember, those channels would run--would run with the deep veins. (Appendix E:245)

There are 9 such occurrences of will and 9 of would. There is one idiomatic use of will and 8 instances of would like:

> And the rest of these slides--I'll tell you what, we're going to cut it off at this time, I think. (Appendix D:228)

> I really would like that to come from you. (Appendix A:129)

There is a use of MAY which seems to fall somewhere between deontic modality and nonfactivity. It seems to indicate "what is permissible or allowable" under certain circumstances, e.g.,

> The vein lies behind or medial to the artery; it may be removed, if desired, in cleaning the artery and its branches. (Tobin 1951:221)

There are 2 such instances in the spoken data and 8 in the written. There is one closely related occurrence which seems to be an instruction:

> When these have been seen they may be cut so that the muscle may be completely reflected. (Tobin 1961:222)

The one occurrence of used to has a habitual sense, similar to subject oriented would:

> It used to be fairly common in Fortran that you would have to do something uh like this--um like this. (Appendix A:135)

Twenty-five of the modals were not classified either because they seemed to have such a mixture of meanings or because the context was not clear.[1]

Summary of Modal Meaning

The meanings, as classified in this study, are listed in order of frequency in Table 5-15. The number of tokens and percents are provided for the spoken and written data.

Table 5-15
Summary of Modal Meanings

Meaning	Spoken Tokens	Spoken Percent	Written Tokens	Written Percent	Total Tokens	Total Percent
Dynamic	406	36.94	144	31.71	550	35.41
Futurity	257	23.38	24	5.28	281	18.09
Epistemic	131	11.91	93	20.48	224	14.42
Conditional	180	16.37	36	7.92	216	13.90
Nonfactive	6	0.54	45	9.91	51	3.28
Existential	23	2.09	4	0.88	27	1.73
Deontic	18	1.63	2	0.44	20	1.28
Rules	0	0.00	9	1.98	9	0.57
Rational	5	0.45	1	0.22	6	0.38
Other	57	5.18	88	19.38	145	9.33
Unclassified	16	1.45	8	1.76	24	1.54
Total	1099	99.94	454	99.96	1553	99.93

The most common overall meanings are dynamic, futurity, epistemic, and conditional/unreal. The same four meanings are also the most common in the spoken data, with the order of the last two reversed. For the written data, the most common are dynamic, epistemic, other (mainly the use of <u>should</u> in instructions), and nonfactive. Palmer's system, therefore, accounts for 1384 or 89.11 percent of all the meanings, all except those grouped under "other" and "unclassified."

Note

1. Following is a list of the unclassified modals in their respective utterances or sentences:

Spoken: I see no reason why you can't. (Appendix A:145)

Okay, now we can look at another one of our contraints. . . . (Appendix C:185)

And the neuron membrane uh can be thought of as made--being made up of little patches of membrane. . . . (Appendix F:273)

Um the motor unit pool can be thought of as being made up of three or four individual motor unit types. . . . (Appendix F:289)

And, say, if I don't have to reserve that register, I can use it for something else because of the way through your--the uh program may be implemented in that situation. (Appendix A:131)

It may not have the strength of the crushed stone base, but it allows you to build up here over a weak subgrade. (Appendix D:219)

And so that suggests that uh there are characteristic differences of rheobase by unit type that are not caused by any relationship which may exist between rheobase and input resistance. (Appendix F:296-7)

I thought I might mention that. (Appendix B:177)

So this is--is, and you see, uh represents a front view of the--of the hip-bone, and the femur and the tibia and the fibula run into--might--might point out that uh--that this is the greater trochanter here. (Appendix E:259-60)

Uh might mention this. (Appendix E:262)

Um something I might mention that is probably of functional significance to the after-hyperpolarization. (Appendix F:297)

And then you might have zero point four seconds for the uh rest time. (Appendix D:203)

So I can now, let's see, the type of that node then is, since I have an R and a D being mixed, will be what? (Appendix A:140)

And if you could look into that area, that is the space between actually, the inguinal ligament and the vein, you'll see a ring there, and that's just called the femoral ring. (Appendix E:253)

Which would you prefer? (Appendix B:155)

Well, that's--it probably would. (Appendix B:171)

Written: Thus, when Eq. (10-11) is used to add new query terms to relevant documents, these new terms might be added with decreasing weights. . . . (Salton 1975:490)

As an example, a compiler's symbol table might be implemented as a dynamic array. (Blake 1977:31)

They might be any logically adjacent register pair. (Blake 1977:37)

They do it through an understanding of how the system will actually be programmed. (Blake 1977:30)

A little scatter might be anticipated, since variability in recruitment order has been observed in direct comparisons of motoneurons whose CFLs differed by less than 2.5%. (Henneman 1980:728-729)

Frequently there will be a choice of aggregate sources or of areas within the same general source. (Asphalt Institute 1974:73)

Select the lot size--it can be time (hours), an average day's production (tons), a selected tonnage (example: 2000 tons), or a selected number of truckloads. (Asphalt Institute 1974:66,68) (This sentence occurs twice.)

CHAPTER VI
APPLICATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Although the findings in this study are based on a carefully selected, relatively large data base, we cannot make sweeping generalizations. We must acknowledge that only six hours of class lectures were recorded and only six reading assignments considered. Based on these data, however, we can note tendencies which can be taken into consideration in teaching and preparing materials for EST.

The findings in Chapter IV indicate that spoken and written data do differ in the frequency with which modals are used. The findings in Chapter V indicate that certain meanings are more frequent than others. This information allows us to determine which meanings of each modal tend to be most frequent in the spoken and written data. This will give an indication of which modals and meanings to stress in EST teaching and materials preparation.

The most common spoken modals are <u>can</u>, <u>will</u>, <u>would</u>, <u>going to</u>, and <u>have to</u>. The number of occurrences of their various meanings are summarized in Table 6-1.

Table 6-1
Meanings of Most Frequent Spoken Modals

Meaning	can	will	would	going to	have to
Dynamic	212	62	6		90
Futurity		89	1	167	
Epistemic	1	13	60		
Conditional		23	125		
Nonfactivity					
Existential	3				
Deontic	6				
Rules					
Rational	2				
Other		29	17		
Unclassified	4	2	2		
Total	228	218	211	167	90

Thus it would seem that for students studying spoken EST, we would want to emphasize the dynamic uses of can, the future and dynamic uses of will, the conditional/unreal and epistemic uses of would, the future of going to, and the dynamic use of have to.

The most common written modals are may, can, should, will, and must. The number of occurrences of their meanings are summarized in Table 6-2:

Table 6-2
Meanings of Most Frequent Written Modals

Meaning	may	can	should	will	must
Dynamic		85	5	16	24
Futurity				22	
Epistemic	37	3	8	25	6
Conditional			2	12	
Nonfactivity	45				
Existential	2				
Deontic			1		
Rules	9				
Rational		1			
Other	8		72		5
Unclassified	1	2		2	
Total	102	91	88	77	35

Thus it would seem that for students studying written EST, we would want to emphasize the epistemic and nonfactive uses of may, the dynamic uses of can, the use of should in instructions, the epistemic and future uses of will, and the dynamic use of must.

This information could, for example, be used to supplement the material on modals found in Jean Praninskas' (1975) Rapid Review of English Grammar. In that text, Lesson XIV contains six pages listing modal meanings, acknowledging that "the meanings of modals are very complex indeed" (234) and suggesting that "the best way to master the use of modals is to observe how they are used in situations and to practice making sentences like the ones you hear, always making absolutely sure of the meaning of what you are saying" (234).

Praninskas does not indicate which uses are more common or which are more likely to appear in spoken as opposed to written situations. She does not, for example, indicate that going to is more common in spoken than in written English. She simply states that it "is probably the most common and unambiguous verb phrase used for future" (Praninskas 1975:91).

Simply combining the form and meaning findings with the material in a text such as Praninskas' would still not be enough to facilitate students in their learning of English modals. Lackstrom (1979:55) summarizes the problems he has encountered in teaching modals in this manner:

> There is first the sense I have had from my students that the semantic labels I put on the modals are less than fully understood in any but a very superficial way: labels like "obligation," "ability," and "necessity." There is, of course, the problem of the ambiguous and overlapping meanings, which seem to raise more questions about differences in meanings than there are answers to give. Finally, there is the problem of what I choose to call the "overkill" presentation. This is the presentation in which you begin "Today (This week, For the next two weeks, This month) we're going to be studying the modals.") Modal over-kill is when you attempt to pull together all the modals into one coherent, elegant system.

To alleviate these three problems, he has three suggestions (57):

1. Use authentic labels which he contends "are those which label performances, not those which label meanings," e.g., an <u>offer</u> or a <u>boast</u>.
2. Separate competing forms and meanings in the syllabus.
3. Spread the modals out across the syllabus.

The findings of this study should facilitate the implementation of these suggestions. (It would not be difficult to add yet another table giving each modal with its various meanings listed according to frequency. This, however, might reinforce the tendency to present students with all the meanings all at once rather than to spread them throughout the course.)

Specific exercises for the presentation of modals in classroom exercises are not presented. Specific

exercises should be selected or prepared for specific situations for the following reasons, among others:

1. Whether or not students have a common language background influences whether or not explanations have to be given in English.
2. A context which is suitable for students in the United States might prove to be detracting to students outside the United States. Even determining if a name is a first, last, male, or female name can be detracting.
3. What students are doing with English outside the classroom influences what is done inside the classroom. For example, students may be simultaneously using textbooks in English as they are studying English.

It should, however, be possible to adapt the findings of studies such as this to specific situations.

Although certain modals and modal meanings may be more frequent than others in the EST data analyzed, this does not mean that the other forms and meanings are to be neglected. The students, for example, may be living in an English-speaking community where they need to ask permission or understand rules and regulations. Also, discourse analysis might indicate that though a modal or modal meaning is seldom used in EST, its use may be crucial. Frequency should not be the sole basis for deciding what to teach or emphasize.

Lackstrom (1979:64) suggests that modal usage is very closely related to discourse and that a relevant separation of the meanings is possible if "the syllabus is based upon discourse and rhetoric and not upon structural or grammatical form." The need for more than form and meaning analyses is apparent.

The next step in the investigation of modals in EST should probably be in terms of a rigorous discourse analysis. This should begin to answer questions concerning, for example, why certain modals are more common in certain data. Even if we just consider the brief summaries of the spoken data provided in Chapter III, we can gain some insight as to why future meanings are characteristic of the spoken data. In four of the six lectures, a noticeable amount of time was spent discussing future classes and assignments. It is reasonable that the expressions of futurity abound in such situations. The high frequency of <u>should</u> in the written E-2 and M-1 data may be related to the fact that these readings are sections from manuals which give instructions. Discourse analysis of these data will be of use in determining to what extent judgments indicating predictions, conclusions, suggestions, and reasons use epistemic modals.[1] That is left for a future project.

Note

1. Some discourse analysis on modals in EST has been carried out. Lackstrom (1979) has studied the use of <u>can</u> and <u>may</u> in written reports. Ewer (1979) has carried out work on modals in articles and academic lectures. Modal analysis in terms of the rhetorical processes as analyzed by Selinker, Todd-Trimble, and Trimble (1978) would probably be highly beneficial to those interested in EST.

CHAPTER VII
SUMMARY AND CONCLUSION

The purpose of this study was to investigate the frequency of modal occurrences and meanings in scientific and technical English as used at the graduate level in an American university for possible applications in teaching and preparing materials for EST. The data base consisting of 80,000 words, half spoken and half written, was collected from first semester graduate courses in computer sciences, engineering, and medicine at the University of Florida.

Definitions of EST, modal, and modality are discussed in Chapter I. This chapter also contains a brief sketch of the historical development of modals as well as summaries of studies by Block 1947, Boyd and Thorne 1969, Lakoff 1972, and Marino 1977.

Three data based studies are discussed in Chapter II: Joos 1964, Ehrman 1966, and Palmer 1979. The framework of Palmer's study is presented in detail and serves as the basis for the form and meaning analyses in this study.

In Chapter III, the data collection procedures and analysis methodology are discussed. The six hours of classroom lectures which provide the spoken data are

summarized as are the corresponding written data from reading assignments for these lectures.

The form frequency analysis is presented in Chapter IV. The data base yielded about 1550 modals, 1100 spoken and 450 written. In these data, <u>can</u>, <u>will</u>, <u>would</u>, <u>going to</u>, <u>have to</u>, and <u>able to</u> are more characteristic of spoken EST while <u>may</u>, <u>should</u>, and <u>must</u> are more characteristic of the written data. There is a higher percentage of modals in spoken finite verb phrases, 22.95 percent, than in the written, 15.89 percent. Written medical material may have fewer finite verb phrases with modals than other types of EST. There is a higher percentage of passive verb phrases with modals in the written data (58.05 percent) than in the spoken (4.16 percent). Contractions are very common in the spoken data but nonexistent in the written. It is not unusual to have adverbs within the modal verb phrase nor to have modals with two verbs. Tables and statistics supporting these findings are provided in this chapter.

In Chpater V, the analysis of the modal meanings according to Palmer's (1979) framework is presented. Overall, the most common meanings are dynamic (those which indicate that an event is possible or necessary or that the subject has the ability or willingness to do something), futurity, epistemic (judgments about propositions), and conditional/unreal. In the spoken data, the most common are dynamic, futurity, conditional/unreal, and epistemic.

In the written data, the most common are dynamic, epistemic, the use of <u>should</u> with instructions, and nonfactive. Palmer's system turns out to be quite efficient in that it accounts for about 90 percent of the meanings. Tables and statistics for these findings are presented in the chapter.

Possible applications and suggestions for further research are presented in Chapter VI. It is suggested that the most frequent meanings of the most frequent modals be emphasized while not neglecting the others. The findings can be used to facilitate the implementation of Lackstrom's (1979) suggestions for improving the efficiency of the teaching of modals in EST. It is suggested that the next step in the investigation of the use of modals in EST should be in terms of a rigorous discourse analysis.

Additional form and meaning analyses combined with discourse analysis should enable more efficient teaching to take place and more appropriate materials to be prepared.

APPENDIX A
COMPUTERS 1

(L: Lecturer; A: Audience)

L: Okay. We have a visitor in our midst, Nellie Sieller, from linguistics I guess it is.

A: Right.

L; Right? I remembered it. Uh she's a Ph.D. candidate, and she wants to record the--uh what goes on here today as part of her--as part of her research. So don't allow it to inhibit you in any way. Just carry on--

A: . . . .

L: as--the way we would under normal circumstances. Uh maybe at some point we'll hear more about what Nellie's research is, but at the moment this is just a part of her data collection base--linguistics.

A: . . . .

L: Okay. First of all, what I've been trying to dig up are some interesting papers on optimization, code optimization. I think I've come up with the set of papers that I need. This is going to form a base from which you are going to prepare your mini uh presentations on optimization. What--and the minipresentation--what you're going to be--you're going

to end up with is a very small unit from one of these papers. So I would think that three or four people would be able to get something from this particular paper. This one I'm not overly enthusiastic about. It's an IBM paper on an experimental compiling system. It's not about a particular compiler. It's a compiling system. So a compiler compiler. Um it didn't exactly reveal all of the things that you need to know, but there are some interesting aspects of this. And uh when they talk about optimization within a compiler compiler, that opens up a whole new area of problems; how you come up with a semantic specification of a computer and have it--and automatically generate the compiler and have it to some extent optimized is a serious problem. Uh this other paper addresses, an IBM paper, addresses somewhat the same problems, and it's optimization of a compiler for several machine architectures because when you start talking optimization, remember, there are two levels of optimization. One, it's sort of a machine specific optimization where you discuss, and you try to do things well on a particular machine, and others are non-machine specific. The fourth paper I have selected is one for optimization and code generation for a stack machine. And this is sort of the simplest case 'cause here you take the machine that it's very easy to optimize for, except maybe if we could

op--if we were able to generate a code for a stack machine, how could we optimize that code? The other ones we're looking at are more--are more realistic, more pragmatic approaches to things in that they're taking existing machines, machine architectures, and saying, "How can we generate this particular compiler for that particular machine and--and optimize it?" And there are studies, and there are reports on studies on various optimization techniques that have been tried and the results. Could we organize something to allow those papers to circulate so that people can get a chance to copy them, have a chance to look at them? Uh how many of you people share the office over on the second floor? How many people are in the same office?

A: In the stadium?

L: Yes, in the stadium. There's three, four, five--

A: The biggest number are there.

L: Okay. Maybe if we take the uh take these, and if you could keep them over there somewhere. You have a--put them off on a bulletin board someplace where no one's going to--

A: Hey, how about in the library?

L: In the library?

A: Library, the reserve room. . . . They've got enough copy machines there.

L: Lee, you've got yourself a job. Get these four papers into the library. Get them on reserve, under this course name, and uh organized.

A: Now what are we supposed to do with these besides read them?

L: Okay. We're going to pick--you're going to pick a--a topic from there for about a fifteen minute mini-discussion, in class, where you will present one interesting concept from the paper. Uh so what we'll have to do is--well, at the top of each paper, you'll see I've made a little notation as the number of units that I expected from each paper. Three units means I would expect three people to get something out of that paper. Maybe if you choose something from the paper, if you write your name at the top saying, "I've selected something from this." And then you might get together with the other people who have also selected the material to make sure you're not Xeroxing the same one--the same thing.

A: . . . .

L: I have not made any notes inside as to what I considered to be interesting things. I really would like that to come from you.

A: . . . .

L: Remember that I'm talking a fifteen minute presentation which means at most, what? Two slides? That's about it--that's about it.

A: . . . .

L: Yeah. Sure. Fifteen minutes. Maybe three. You don't get to say very much in fifteen minutes.

A: . . . separate folders, it would be nice. . . .

L: Well, you want to organize that?

A: . . . .

L: You can uh get some--one of the secretaries up in the office to give you four Acco press folders, put a little label on it, the course number, and what it is, something of that nature, so that there's a nice--a nice professional job.

A: . . . in choosing an interesting point uh from a particular paper, uh should this point be independent enough where you don't have to do any kind of lead in into it, or can you coordinate with another person on two major units?

L: You would probably be most effective if you coordinated with someone else.

A: Okay.

L: Let me just take one--one example from one of the big papers where the factor--in one of those larger papers--

A: . . . doesn't have any factor.

L: Well, make that a two unit, the stack machine.

A: We have to coordinate this to make sure we don't overlap.

L: In this experimental compiling system, there's an interesting discussion of what they refer to as flee--flee problem--flow free analysis. And what they've discussed there is a way for a compiler to look at the

flow, the actual flow of control through the source program and make some decisions, some optimizing decisions, based upon things that are actually happening in the program. It can look at it and say, "Ah, obviously, if you use this particular variable, you can't be using this next one." Therefore, it's allocated a register for one variable. And, say, if I don't have to reserve that register, I can use it for something else because of the way through your--the uh program may be implemented in that situation. Or, they look and say, "Well, I've got a--a variable that's initialized at the very beginning of the program and is used continuously throughout the program." An optimization technique might recognize that and allocate a register for it. Another mechanism might recognize that uh you initialize or you use something very early on in the program, and you never use it again. You never refer back to that particular variable again. Therefore, it might not allocate an independent register or uh dedicate a register for that particular variable. It may have a temporary register. So it has to be reinitialized every time it's used because the compiler can recognize the fact that it's a low usability--low utilization variable. So things like that are uh of interest to the compiler when it's talking about optimization. All right, we have to back up from optimization at the moment. We're still

talking in terms of types, implementation of types, at compile time and at run time. The motivation for type, as we were discussing before, is the fact that the user does not have to know what the implementation is. When you describe something as being typed for array, there's no reason for the user to be concerned about how arrays are represented. There may be some sparse array representation, or the arrays may in fact be represented on some secondary storage device. It does not matter to the user as long as the user has access to the arrays. What is of interest, though, is that if you have types available to you in the program, it means that the programmer has the choice and has to be able to make some intelligent choice. It also means that the compiler, when it looks at a symbol like plus sign, minus sign, has to decide what kind--what type of operands can be operated on by this operation. So, along with each type, there will be certain operations that are permitted. An operation will result in a variable of another type of some type. So these problems have to be resolved within the compiler. Warning messages. As far as the compiler is concerned, if there are certain violations of the typing that can occur, the compiler has to be prepared to produce warning messages or error messages to take necessary fix-up steps. Things like equivalence and common are disastrous if you're talking about a

language that's trying to enforce some kind of a typing. Uh for example, in Fortran we have the equivalence. You can equivalence things even though they may not be of the same type. Of course, the only way that that kind of equivalencing can have any kind of validity is if the user knows what the mapping is and what the correspondence is between these different variables even though uh they may be declared to be different types. One might be declared to be character, and the other might be declared as real. As long as you know the format of how a real is stored in this particular implementation, then you can do that sort of thing. But for any language that tries to enforce typing, you're just not going to have those constructs available to your compiler. Common does the same thing. Boolean operations on uh things that would ordinarily be quantitative variables, doing AND operations on a couple of integer variables. You just would not be able to do that in a language that forces typing. You would say uh, "Boolean operations are for Boolean variables." You can't AND two integer variables.

A: . . . Backing down to one point--

L: Yeah.

A: I couldn't really follow why the uh fact that you're forcing typing does not allow you to uh write equivalence statements on this.

L: How about this? If I equivalence these two variables, I could do this, but then I would have to assume that I know something about the storage of these things. I would have to know that a real is stored, perhaps, in a double word whereas an integer takes uh a whole word. So that by making this mapping, this equivalence, between E and I, all it's giving me is--it's not equivalencing the attribute, any other attributes, other than the address attributes. So what I'm saying that--is that when I'm referring to E, I'm referring to this memory location. When I'm referring to I, I'm referring to the same memory location. So, the only attribute that it's acknowledging is the location, storage location. It's not acknowledging the type attribute which means, then, for the programmer to make any use of this, you have to know something about the implementation of these types. And that's what we're trying to get--get away from, where we want the compiler to be able to choose the best possible implementation for each of these types. You look at a Fortran manual. A Fortran manual will have to describe somewhere the order in which various things are stored in uh in memory, how things are stored in a word, and all that has to be discussed in a Fortran manual. That does not have to be discussed in a Pascal manual because in Pascal the implementation is hidden from vision. Arithmetic with character variables.

It used to be fairly common in Fortran that you would have to do something uh like this um like this.

A: . . . .

L: Hm? You take I or I minus character zero where you take the AST representation zero, subtracting it from something that you know contains the AST representation of some other digit in order to get the numeric value of it. Of course, if you're mixing types here, you're using an integer variable to encode what's essentially a character. But now you're going arithmetic between the integers and characters, which you can get away with in Fortran. Fortran will give you the integer equivalent of--the AST equivalent of this, and it will subtract it from this thing. And you'll end up being able to do the arithmetic, provided you know something of the implementation of these variables. And the implementation will involve various things like whether the blanks are stored to the left of the word or the right of the word, things of that nature. In Pascal, you would have to use some other function. Uh look at the order function. You could say uh you can pick up the order of some character variable C, and what ORD gives you is just a sequential numbering from zero through uh two fifty-five throughout the whole collating sequence. So, for any character there is a number that will be returned from the ORD function. So, if I asked for

ORD of the character A, it would give me a number. ORD of the character B would give me the next number. ORD of the character C would give me the next number. Each number will have an ordering associated with it. But, then, how to implement it is really of no great concern to the programmer as long as you can get an integer back.

A: . . . wouldn't it be easier if they just do a type transformation on this here?

L: Yeah, exactly. But, what we're saying here is that you can have two or three types of--of implementations of these. One in which you can do any operations between any types and get the conversions taking place by the compiler. And, say you want to subtract a character from an integer, you can take care of it. PL-one would do that. Or you get strong typing where, like in Pascal, where things have to be of the proper type for whatever operation you want. Uh other things that you can't have if you're going to use a lot of strong typing, if you want the compiler to type things from the user, is uh parameter passing by reference. Passing by reference, you're passing an address. And, that's the only attribute that's given in the subroutine--is the address of the actual parameter. Whereas, in fact, you want the subroutine to be able to have information about the type of the parameter so that it can implement its uh type checking. In-line

assembly poses another problem. There are some languages that allow you to be going along writing a high level language, and then immediately switch into assembly language in-line. The problem there, of course, is that the programmer would have to know something about the implementation of these things. So these, and a lot of other things that people say, "Hey, but that's why I use Fortran is because it gives me access. It allows me to uh to do this sort of thing, to mention a variable." You can men-mention a variable this way, and later on what would happen if in your program you referred to--

A: . . . .

L: Okay. This will be referred to. You're actually using the fact that you can uh reference something you know is beyond your particular array bounds, and it's going to give you a fixed location in memory. But again, all this resolves for you in Fortran is an address. It gives you the address attribute and nothing else, and the fact that you can generate address, any address you want. You could put it--

A: . . . .

L: Yeah, then you would have to put something specifically in your compiler to turn on the flag that says you want an array bound checking, and then it would check for this at runtime. But, otherwise, it will happen. It will generate an address and just put that number

through the computation and the subscripting. You come up with an address reading. Pascal, on the other hand, will check the array to make sure that it's in the bounds that you've specified, for whatever type you said.

A: . . . why didn't you say one twenty to begin with?

L: Pardon?

A: Why . . . wouldn't it have said. . . .

L: Yeah, you might know that it's going to be at least a hundred and that any more than that is going to be slopped over into some other array. Or, quite often when you're writing subroutines, you write a subroutine, and the only information you have coming into the subroutine seems to be dimensions. So you make it this. It doesn't matter what number you put in because you're being passed the array as an input array. So you don't really know how big it is, nor do you care how big it is. All you really want to convey to the compiler when it's compiling the subroutine--you want to tell it that it's an array so that now the compiler knows that when it generates references to this thing, it must resolve the subscript. The fact that you said one here means absolutely nothing to the compiler. A lot of people write subroutines that way in Fortran.

A: . . . equivalent to star in PL-one, PL-two, isn't it?

L: Not really.

A: It's not?

L: No. No, this is not equivalent to anything.

A: . . . it's just really poor programming.

L: Yeah, it is. But Fortran engenders a lot of this because it allows you to do things. It allows you to do these equivalences. And, people will take advantage of it. And then they'll get to the point that they say, "That's what I like about the language is the fact that it allows me to do these things." And what they're saying they like are the very things they should be avoiding. Okay. Well, one of the problems that you run into and that has to be resolved in the compiler is generating a code form, a typed expression. Suppose I have an expression, a code. Take--before I do that computation, where this is a complex type, this is integer, J is integer, R is of type real, and D is of type double. Well, Fortran, of course will allow you to do that. There are different rules that you can uh implement in a compiler to allow mixed-mode arithmetic. The fact is that you're not going to be able to do this division directly. You're not going to be able to divide a real by a double. So there's going to have to be conversions. There're going to have to be. The operation will have to be done either as a real or as a double or as something. So, then, we implement a hierarchy of the types, and end up with something like this. If we have a

mixed-mode expression, and it involves integers, reals, doubles, and complex variables, we'll rank them and say that an integer variable is lower priority than a real which is lower than a double which is lower than a complex. So, given a combination between--of any two types with which to do an operation, we'll migrate to the type that's highest in this hierarchy. So, if I have a real and a complex, I'll go to a complex operation because anything that I can represent as a real, I can represent as a complex without throwing anything away. Whereas, if I had--went to the real type, I'd have to throw away something from the complex of what I can represent. So we make a hierarchy like that. So then we end up with our--the AST that we would have generated from this thing when we were parsing it and trying to generate the code--would have ended up with something like this. We'd've had the assignment statement as the top of our tree and the addition of I plus something that was derived from the product of J times something that's the division R divided by D. So, in doing the transversal of this thing, I see that I've labeled these things by the type of the operand. So here I have an R and a D as the leaves--leaves on that node. So I can now, let's see, the type of that node then is, since I have an R and a D being mixed, will be what? This'll be a double. So this node, then, can be

flagged as being type double because I've got a mixed operation between a real and a double. Now, when I look at this multiplication, I see that--that what I'm multiplying is an integer and a double. So now I'll have to mark this node as being a double. Now I've got an operation between an integer and a double. So I'll mark this node as a--being a double. In an operation between a complex and a double, I have--for an assignment operation, I'm stuck. I can't go to the highest representation. Right? For an assignment, I have to go for the left--the type of the left-hand uh leaf. So, in this case it's C. So I would have to make this node a complex assignment. So now I can take a look at the tree, and I see that I've got a few conflicts to resolve. Here I'm trying to do--do a double operation, but this R is the real. So when I'm generating my AST, I'm forced to insert an operation. So as I generate now, I just scan through my AST when I'm generating my codes. I see I've got a conflict between an R and a D node. So I put in a conversion. So this'll be just a real to a double conversion. That will make this a double node. Now I can do this--this operation. I've got a double divided by a double with the insertion of one uh conversion operation. To come up with the multiplication, I see I've got a double and a double. No problem. If I had a double and a real, so I'd have to insert another

conversion. I'll insert a conversion operator at this point. And I can decorate my tree now by sticking in these, or enhance my tree, augment it, with these uh conversion operations that can be generated by the compiler based on their AST that was generated using the types as uh given by the programmer. So in this way, PL-one does this sort of thing. Fortran. Cobol. Basic? Yeah, Basic does it.

A: What's Pascal do?

L: Try to add an integer plus a real.

A: . . . .

L: To do which? So you call that a type?

A: . . . .

L: How do you force it?

A: . . . .

L: So if I tried to do this type of operation, where I've got an integer and a real--

A: That's okay.

L: That's okay?

A: . . . .

L: Shall I try that assignment to an integer variable?

A: . . . .

L: You think that's a problem? I don't think so. That would make sense. It would say that this is--that it would allow conversions down in this lower part of the tree operations, but it won't allow the uh downward conversion at an assignment because there you're

losing something. But you can build your functions so that it can give you these kinds of conversions.

A: What's that funny little thing that J runs into?

L: Funny little thing that the J runs into?

A: . . . what is that--that little circle that the J--

L: This?

A: No, up, up a little farther.

L: Okay.

A: No go. . . .

L: That's an asterisk, multiplication.

A: . . . I thought there was supposed to be a minus there.

L: Oh, maybe there was.

A: . . . .

L: There was a minus in the uh--?

A: Yes.

L: Okay. Different function. Okay. Thanks. Decorate my assignment. Okay, so we can do that with uh typing, and there's no real problem. Another type that we encounter rather than . . . with the structures. Structures are a bit more interesting because there your compiler actually has to learn to recognize some things. What I'm going to do is build myself a structure. It'll be a . . . build one. Suppose I have a structure that looks something like this. Level one, I have a name, A. And at level two, I have a couple of names. I'll have a B and a C. And . . . one here. At level three, all right, I have a C and a D.

And at level two, I have a C. So it's just a structure in good ol' PL-one, I guess. I can clear those things with no problem. How can I refer to things? Suppose I want to refer to that variable, what means can I use to refer to it?

A: D.

L: D.

A: E.

L: A dot B.

A: A dot B. . . .

L: Okay. I can use a complete specification of the name, or I can use a partial specification of the name as long as it's unique. That means that we have to build this sort of thing into the compiler. And what it's building, in fact, is recognition of a small language. Normally, this is implemented within the compiler by having the compiler build an FSM to recognize the needs. It's uh you just take the whole structure, build--let's see, let's build all the partial names. Uh let me put something else in here that's not even part of this structure. Oh, why not do this? Can I do this? C? Okay. I can have that as something else. I can refer to this as C, which means I have to refer to this one as A dot C. Now I have to tell the compiler what names it can recognize--what names are acceptable, what aren't acceptable. What I can do is build a list of all partial names, first of all. And what are all

of the partial names? Uh I think I've got too many here. A is a partial name. Well, any name, B, C, D. Those are all partial names.

A: . . . what about C. . . .

L: Oh, I'm not saying this is a complete reference. These are partial names that I can--

A: Well, yeah. . . .

L: Okay, let's take it from the beginning then. A, A dot B, A dot B dot C, and A dot B dot D, and A dot C, and A dot D, and A dot--oops, that's A dot C, and C. Is that it? That's not bad.

A: . . . .

L: B dot C, B dot D.

A: . . . .

L: That's what they seem to be saying, oh.

A: . . . .

L: I see no reason why you can't.

A: . . . .

L: Oh, C, yeah, that's not really unique. If I refer to it here, no.

A: . . . .

L: But not with this C.

A: . . . .

L: Okay. So, what do I have to do now?

A: Now . . . are you saying this is something the compiler will construct. . . .

L: The compiler is going to have to construct this because this--you can't construct this FSM until you've got

the structure, and so this is going to be something the compiler is going to be doing at compiler time. What I'm trying to figure out is what are valid references for these different names? So if we construct--I've got this thing much too large for my purposes. Okay, let's see what we can get. Uh I'm going to construct an FSM where I've got a state for each one of these par-partial names, and I'll make my transitions on uh other--other uh individual names. So I'll be able to make a transition on B. I'll be able to make a transition from A to A dot B. So I'll have a state for each one of these things. Then I can make my transitions based on the uh the uh name. There are certain complete specifications. A dot B dot C, A dot B dot D, um A dot C, and C. Those are complete specifications for some of these. And I can add another start statement. I don't know if this machine is going to work out or not. Put in a start state. From my start state, I can get--where can I go? I can get an A, or I can get--from my start state, actually, the only thing I can get to get a complete specification is either an A or a C. In this case, I'd take a C. If I get an A, from an A, I can get either a B or a C. Is that right?

A: . . . .

L: Now, I'm not going to put the whole thing in yet. I'm trying to build uh complete names first. A dot B and

A dot C. And from there, where can I go? From A dot B, I can go either a C or a D, to an A dot B dot C, or to A dot B dot D. That would give me complete specification. A dot C is a complete specification. But, of course, this just gives me the complete names. It doesn't cover the partial names yet. Okay, now what I have to do is find some way to build in the partial names that are possible. What I can start doing now is enhancing this FSM by saying, "Okay, from the start state now--." Oh, first of all I mark my--my--my accepting states. I've got one, two, three, four accepting states. One for each leaf in the structure. No problem. I'm going to rebuild my machine, and in my new machine, I'm going to have new final states. I'm going to have some extra final states included here. And let's see, what I'm going to do is create this one by going from--you take any path through here. You take this path. It starts off with A through B and through C. I look at this path and say, "Okay, there are different ways that I can traverse that path." One possible way to traverse the path is to go straight from S to A dot D. I can go from S to A dot B on a symbol B. And I would mark this as--not as uh an accepting state, but as a new accepting state. So, how am I going to mark those? I think I'll put two raised dots. So that's a new accepting state, but not an old accepting state. Also from here, on a C, I can go out

to the end, and then I'm going to have to mark this. Mark it this way. On a C, I go to A dot B dot C. Puts another branch on this one. That's fine. Now I can make a transition C. I can make a transition uh if I get a C. It brings me from a start state--state to points A dot B dot C. If I get an A, it brings me here. If I get a B, it brings me around to this state. And that's no problem. And I can do this for every other path. Let's see, what else can we do? From A, I can go to B. From A, if I get a C, I can also go up to this point. All right, so I'll have to add another path in here going from node A back out here on a C coming into A dot B dot C. No problem. I can do it from here. So, now I've added some extra transitions, and I've got a machine that's no longer deterministic. Yes.

A: That S. . . .

L: That's right. How do we detect that?

A: . . . .

L: It's not deterministic. When we start going through this, through the--the procedure to make it deterministic, what's one of the first operations we do? Okay, after we get rid of empty moves and all that stuff, we collected states. All right, we made composite states. So I would have to make a composite state from this and this. That's how I detect that I've got a problem. Okay, if my machine ends, if I

start going through here, and I end in one of those composite states, then I have a problem that has to be resolved. I've got an ambiguity. If I end in a noncomposite state that is a new terminating state but was not an old terminating state, then I have incomplete reference. All right, so if I got from the start state, if I got a character B, it would leave me here, which is a new accepting state but was not an old accepting state. So, I now know that this is not a complete specification. It's a partial specification, part way down the tree. So it's still referring to a structure that did not have an entry item. So that would have to be an activity specific to within the compiler. If I reach something that was an old uh accepting state, and is not a composite state uh like this one, an old accepting state and it's not a composite state, then I'm all right. So, when I get a line going from S on a D, will point me here. It'll bring me into this state which will be unambiguous. Uh there'll be no problem at all. Okay, so by running this machine, putting it through the algorithm to make it deterministic, and then grabbing some information from that algorithm, we can find out how to parse these things so that when we get a reference, like B, or C, or A dot C, you can run it through your machine. And A dot C will go through this machine as A dot C. You'll end up in that state. Now if there's

something else that could have given you an A dot C--there was. An A dot C could have brought you there, so that when we made this thing deterministic, A dot C would have been a compound state--would have been a combined state. So I--I landed there, and I say, "Ah! I have something that's a bit of nondeterminism." Then I would have to be--resolve it. I could resolve it by saying, yes, for one of the things in that composite state was an old accepting state. Therefore, I will resolve it by saying that's what the reference is. Okay, and that's the way the PL-one works it out. Are you--would you be allowed to have this structure? Where you could refer to A dot C?

A: It's ambiguous reference.

L: Okay, how would it know that it's an ambiguous reference?

A: There would be a combined. . . .

L: What I'm saying is you can mechanize--you can mechanize the recognition of the partial names for this structure. You can mechanize the process of recognizing ambiguity in references, and incompleteness in references, and resolve them however you want within a compiler. But you can recognize them very easily by having the compiler generate little FSM's as it's going. So, what we have here is a compiler that's in essence defining a little language and writing its own little

compiler or recognizer as part of, and as a very small part of the compiler. Like it'd just be one little routine. Uh well, of course--so much for today, isn't it? Where we're supposed to be today, talking about run time structures, and where we didn't get to yet, takes all of these things and looks at them not so much from the compiling point of view, but what happens after you get them compiled and how can you set these things up at run time. The model that's used is a stack machine. It's a machine that's a--that has the capability of running a language like Algol, in which case, we're generating Algol object code. And what we take a look at throughout that whole chapter is generating various uh program constructs in this Algol object code which is, say, generating it for a stack machine. At least those are the structures that we're going to have to look at for the rest of the week. That's all.

A: . . . .

L: Okay. Any questions on this now? Any comments, uh?

A: . . . this goes back to the beginning of class for the mini-presentations. What dates did you want us to think about?

L: Oh, yeah, the week that we're looking at or that we're talking about chapters eleven and twelve, but if it slips over into that last week, there's no real problem. So, if you want to organize two or three of

you to be in a certain sequence, you can have--like--you can do them all in the same day, or you can have consecutive days.

A: . . . .

L: So, we'll make up a schedule, and uh maybe next week, we can have a schedule drawn up. Because we will be looking at these details. The problem with optimization is--is that a good portion of optimization is so machine dependent that it's not the sort of thing you can talk about for any amount of generality. You sort of have to dive in and say, "Well, look, let's look at things for this particular machine." That's what a couple of those papers do. Anyone still working on that program?

A: . . . .

APPENDIX B
COMPUTERS 2

(L: Lecturer; A: Audience)

L: I think it's time, isn't it?

A: Yes.

L: Everybody take a week off for holidays, or what's been happening here? Let's see. I should introduce our visitor. Our visitor is a graduate student from the Speech Department? Is that right?

A: Linguistics.

L: Linguistics. Studying sp-speech patterns in modern American professors or something. Uh okay. Let's see. By way of announcements, uh there is a seminar today at uh two thirty, uh right after this class. Really should attend. It's going to be a real good seminar, I think. Uh Neil Ostlund, who is a uh research associate at Carnegie-Mellon University, will be talking about microprocessor--multi uh multiprocessor architecture. I've got down microprocessor architecture, but multiprocessor architecture: present and future. He's been working on the C.M. Start project at uh Carnegie-Mellon. It's a big, big research project involving uh I think fifty processors--multiprocessing systems, and it's going

to be a real good conference. We're considering him for a faculty appointment either uh here or at uh double E. Uh okay. Let's see. The other thing. I was looking at uh class schedule for the remainder of the term. We don't have uh that many sessions left. Uh I think the--during dead week, I will have project reports, and I think we should be able to do all of the project reports on two days, on Monday and Wednesday of dead week. So December seventh and ninth uh of dead week, why we'll do that and have a review on the elventh. Uh so you might be thinking about project reports.

A: . . . turn. . . .

L: Uh I would like--well, I would like whatever would make a good, full paper.

A: . . . .

L: So uh it depends on--kind of a minimal user's manual. In your case, why uh what you're doing is really a uh a research project. So I know you've spent a lot of time producing things and that sort of thing. More--more I think an outline of what you've done in your particular case. Uh and as far as uh me running it, uh I will--tell you what, I'll--I'll go ahead and do this. Uh I'd like to give you uh say, maybe a week before, I'm going to give you some more data and some more words. Okay.

A: . . . .

L: Uh let's see, Edie, here is your exam back.

A: . . . project report. . . .

L: Yeah, we can do that. Either bring Apple down here or go there. Which would you prefer? It might be easier to go up there. With such a small group, why, we could do that.

A: . . . other question. . . .

L: At the report?

A: . . . something you don't like. . . .

L: It's probably too late to do that.

A: . . . not really. . . .

L: Okay. I'll be glad to do that. Sure. I'll do that. Good. Okay. Want to do that?. . . . When would you like to do that?

A: . . . .

L: Shouldn't ask me that 'cause I always have something to change.

A: . . . .

L: Okay. Uh okay. Uh what I'd like to do today is uh finish up the uh topic that we started last time from chapter ten uh on feedback related techniques. And remember last time we talked about uh relevance feedback as a technique for modifying the queries uh and the information uh retrieval system? And, basically, we would submit a query uh and then uh make some relevance judgments on what we got back. Uh use those relevance judgments--use those--use the

information provided in those relevance judgments to modify the query, and the query would be automatically resubmitted and uh produce a document list that would hopefully be somewhat superior to the uh initial list that's uh that's provided. Uh okay. There is another whole--well there's there's another side to that uh general idea which is described uh kind of briefly in the next section. Uh and that is uh the idea of modifying document space. Uh this is uh uh not something that helps the user initially. It's not something that uh he-helps the person who is making the query, but rather it's something that uh you know, hopefully will uh upgrade the system as--as you go along. Uh the idea again being we're going to uh make--uh uh submit a query, make a retrieval, make some relevance judgments on the documents that are retrieved, and then uh we're going to modify now the descriptions of the documents uh that we have uh that--the descriptions of the documents uh that we've retrieved, both, maybe, both the relevant ones and the nonrelevant ones. Okay. The motivation for doing this, uh as uh Salton points out, there are basically three kinds of motivations for doing it. Uh one is that--that uh in most uh document retrieval situations, why the queries that are made are pretty much the same kinds of things. I mean that, for the most part, uh although they are not identical, but for the most part,

why--why lots of users will uh submit similar kinds of queries, and if you can kind of sharpen this system up for responding to one query, chances are when that similar query comes along at a later date, why uh why uh the system will have enhacned performance at that time. Uh the second kind of general motivation for it is uh to uh keep the indexing current. Uh for, you know--and consider again, you know, having a traditional library system, something that's been uh catalog indexed, uh stored in the document file uh, you know, five years ago, computer literature. Uh changes are that uh uh if the document is of any interest any more, why it's probably of interest for a different reason. I mean, it--it uh may be initially stored as uh a uh document describing some current research or something that's been proposed. Uh and as the uh emphasis of the discipline changes or uh the status of technology develops, why it--it uh becomes of interest for different kinds of reasons. There are lots of . . . and lots of examples. For example, mathematical theorems that are--are uh proposed initially as just theorems and things that become of interest because of some particular application. They're uh they're indexed one way, but their use over time uh may change, uh and uh the initial indexing is no longer appropriate. And so it would be desirable to have uh a scheme that kind of changes indexing over

time on these things depending upon how they're used. Uh those--those are two reasons. A third reason that you might be uh that you might have an interest in doing something like that is just to uh generate optimum weights on uh on document descriptions. You start out, and uh using heuristically defined weights, but after--after uh time, uh over uh many uses, why you should be able to come up with some--some uh better descriptions. Uh at least in theory you should be able to come up with some better descriptions. Uh and we might uh be able to use that uh that relevance information to provide those better descriptions. Uh okay. Well, compared to uh compared to relevance feedback for uh for uh uh modified queries, why uh modifications of the document space is a really unknown quantity. Uh that--there's just very little that's done, uh and although it's got some potential, uh I don't think anybody really knows what uh how eff--well, how it should be accomplished in the first place, and how effective it is. Uh there is an experiment uh described in the book, and, in fact, there is a uh uh--in the book on page uh on pages four hundred eighty-six and four hundred and eighty-seven, why uh there is a--quite a complicated uh algorithm for--for, uh in fact, uh modifying the queries under five different conditions. And uh just so that we think about it a little bit, I--I--I

ought--I think those uh uh that particular algorithm or those particular uh formulas uh have uh relatively little justification. And I think you could come up with another set. He just provides the formulas, and you need to go back and look at the references uh for uh justifying those. But, in general, uh you might think about what uh what the process would be or how you would--how you would uh uh modify the document descriptions depending upon uh the conditions that applied. And let's look at those five uh conditions. Uh okay. So we're going to look at document space modification. We're going to modify the descriptions of the documents. We're going to modify these document description vectors. Uh okay, and we've got two conditions, uh one for relevant documents and condition number two for nonrelevant documents. Okay. Under relevant documents, why we've got three, then, subconditions which might apply. We've got three cases. Okay. In one case, why we might have--now--now, what we're going to be doing is we're going to modify the weights, or we're going to modify the indicator associated with each descriptor, uh so with each descriptor, or with each term. Okay. Now--so we've got three cases. One--in one case, we've got terms that are only in the query, only in the query. Case two, I've got terms that are in both the query and the document. By the document, I mean

this--this relevant document that's been retrieved. And the third, uh terms that are only in the document. Okay. Now, before we go on to the nonrelevant documents, why, then, let's consider these three cases. Uh okay. Again, okay, the idea is this. We take--well, we have the query. We retrieve a document. We make a relevance judgment. We decide that the document is relevant. Okay. Now in the document description, why we've got a list of terms. Okay. Now, let's take a term. Let's look at a given term. Let's assume that the term was in the query. It wasn't in the document. Why uh okay. The term was in the query. Okay. It wasn't in the document. Now if we wanted to improve the probability of--of retrieving that document again using that query, why what would we do? What would we have to do? Hm?

A: . . . .

L: Okay. Good. Good. Okay. We want to put it in. We want to add uh the term to the document description. Okay. Is that clear? Is that what you've got to do? Okay. Now, how you add it, uh you know, is--is the result of one of these formulas, and--and there are, I mean, we'd have to come up with--you'd have to come up with your own sort of mathematical model of how you want to do that. I mean, if you want to add it full strength, subminimal strength, or some function of the number of uh times that uh query occurs or something like that. I mean, I think there are a number of

rational justifications for sev--uh for--for different schemes for uh doing this. Okay. What about if you have a term that was in both the query and the document? What would you want to do?

A: . . . .

L: Mm.

A: . . . .

L: Nothing?

A: . . . .

L: Okay. You might want to do nothing, or you might want to increase the weight, yeah. Anyhow, that's basically a good term. It's basically the good term that's uh contributing to uh that's contributing to the effectiveness of that particular retrieval. Okay. Edie, what if you've got a term that's not in the query? It's a term--a term that's not in the query, but it does appear with a nonzero weight in the doc--in the document description. What would you want to do?

A: . . . won't it affect. . . .

L: Yeah.

A: . . . .

L: I think that's not bad. I mean, that's--I mean, that's kind of the idea, yeah. It's true that it will uh affect other retrievals. Okay. Uh which is--which is also the case with this, right? It's also the case of this. Uh I mean, basically, that's the idea. We're going to tailor it, you know, the things as we go along.

A: . . . because you've. . . .

L: So?

A: . . . .

L: Uh no. Okay. Well, anyhow, as I was saying, there's a lot of experimentation that isn't--still needs to be done, but, I mean, that's what Salton would say, would be decrease the weight. Decrease the weight. Okay. Uh now you might look at it kind of this way, that uh the--it would uh--it would uh uh make some uh uh I mean, you know, there may be a query for which this would be a relevant document. Okay. But, you don't get that query. You--that's not a query--not a query someone uses, and so you--so you--

A: . . . .

L: Right. Exactly. Okay. Good. Okay. Then again, I mean, he's--he's given you three uh ideas here for doing these three things, but uh uh as I said, those are uh there's nothing written in stone on these--these three formulas. Okay. Nonrelevant documents. For nonrelevant documents, why we've got the same--the same two uh that is, we've got two of these three situations that apply. Um first of all, we have terms that appear in the document only. And, Miss Chao, what would we do with that?

A: . . . .

L: What does it make sense to do with that?

A: . . . I don't. . . .

L: Is that--is--is that a uh is that a good term or a bad term?

A: . . . .

L: Oh, but is that--is that term contributing to the overall effectiveness of the system, or--

A: . . . yeah. . . .

L: Yes. It is. Right. So, what would we do with it?

A: . . . .

L: Yeah. Exactly. Okay. That's exactly--it's doing exactly the same thing that this was doing. I mean the--in the first case, why, the term was contributing to finding something that we wanted to find. In this case, why, it's contributing to keeping us away from something we didn't want to find. Okay. So this will uh what we should do is increase the weight in that term. Okay. And the other case that we have is the term's in both the query--okay. And what will we want to do here? Merely decrease the weight, right? Okay. Now if you have your books. Did you bring your books? Didn't bring your books. Okay. Let me describe what he's got. He's got an experiment. Let me just describe it. You might want to read it over, uh but uh he's got an experiment that--that he's described on page four hundred eighty-seven. And, as I say, I think you ought to read it over and look at it a little more carefully, and uh I'll describe it now. But, anyhow, uh uh he has this aerodynamics

collection that he's used in a number of his experiments. It involves four hundred twenty-four documents, a hundred and fifty-five user queries. And uh so, the first thing he did was he pulled out thirty of these queries as a sort of control set, thirty queries that he's going to use as the test set later, and uh uh picked um some parameters of the algorithms which accomplish these things. He picked--picked some, and then he's got some constants in the algorithms that--that accomplish this, five different functions. Okay, and then he went through and processed the other hundred and twenty-five queries, after he took out the thirty. He processed those hundred and twenty-five queries, and uh doing all these things as he did it. Okay. And then the last step was--then he did a uh--he took those thirty queries, thirty control queries, and he processed them against the modified document collection and against the unmodified document collection, against the document collection before he'd made any modifications. And--and he plots the recall precision charts and uh and here are--here are two uh comparative relevance feedback charts. In one case, uh let's see, in this case, why he's just doing the first three of those five things. In this case, why he's doing all five of them. It doesn't make, apparently, much difference if you do--if you do the uh uh if you modify on the basis of the nonrelevant

documents. Uh you know, you get essentially the same graph. Probably not enough data, though, to be able to say anything very conclusive here. On the other hand, compared to most of the uh recall precision charts that you get, compared to, for example, to just a simple first order for relevance feedback where you're comparing two different uh uh similarity measures or uh comparing uh uh two different uh uh word truncation schemes or something, in general, why you get recall precision charts which are a good deal smaller than this one. So that's a pretty good indicator that that might be a uh might be an effective thing to do. Uh as I say, there--there's a lot uh I mean, there's a big need, I think, for a lot more uh experimental work uh a lot more experimentation to determine uh if that is, in fact, the practical thing uh to do. And I don't know of any operation system that makes use of--of this uh kind of a technique. Uh and he also has a discussion uh down here about uh what do you do uh if you want to do this, and you're using, instead of some simple uh straight forward file organization, you're using some sort of a clustered file organization. And that makes it difficult, then, because you have to worry about uh have to worry about how you recalculate the centroids. And uh there's a little discussion in there, then, about--about what you do to the centroids.

Uh 'cause you don't want to recalculate the centroids. You would have to calculate all the little centroids based on everything in the cluster, and, in general, when you can't recalculate them--you can't accurately recalculate them uh on the basis of one modification. Again, you can't calculate the impact on each term from one modification. See what I mean? Okay. So, uh uh they suggest some sort of heuristic techniques for--for modifying that and uh goes through another little test to determine uh uh another effectiveness test to see what uh effect uh these different uh uh cluster centroid modifications have. And uh it turns out--it turns out that uh it doesn't have much effect. Uh okay. Okay. That's what I wanted to do on that. Any questions--any questions on that? Okay. Next thing I want to do is uh going through a little unit on uh microfilm. Uh uh microfilm is uh kind of a dirty word to most computer people. In general, computer people don't like microfilm uh except for a few different--a few applications. But uh for uh information retrieval applications, why uh it's widely used. Uh for information retrieval applications, why uh there are some uh kinds of alternative systems to computer based systems that are uh widely used. And they're uh widely used for the uh the document storage uh function in a information retrieval system. Uh well, so uh I guess what I'd like to do is uh to spend the

remainder of today and uh Wednesday uh just talking about, first of all, what uh sorts of uh well, some of the different forms that uh this microfilm technology takes, and uh how--how it's used, how it can be used as far as the pluses--some of the pluses and minuses of it. And I've got a few uh slides that illustrate some of that, and there's a little book--a little book about uh I'll put up on reserve after class, called Micrographics: A User's Manual--Micrographics: A User's Manual. And it'll be on reserve under this class name. Okay. Well, first of all, as I said, there's a, you know, on the part of most computer people, at least I think there's a kind of built-in resistance to microfilm uh uh for a number of reasons. Uh one is, why, most people feel like, well, it's really something that's used to store--most people's introduction to microfilm comes from uh uh some time when they're sent over to the library to find the nineteen thirty-six edition of the New York Times to see what was going on in Belgium or someplace like that. And you go over, and--and you uh uh first of all, you eventually find it, and then uh uh it's so hard to read that uh uh that uh you strain your eyes, and if you watch it for a while, you get a headache. Uh kind of hard to use 'cause you have to manipulate these readers that are not nearly as convenient to use--to use as computer terminals.

And uh secondly, why, we are uh basically uh I think, trained to look at uh to look at uh design integrated systems where everything kind of works together, and that's kind of hard to do with a--with a microfilm system. Uh I mean, we uh like to store everything on one common, usually magnetic, media uh medium. And uh uh you know, if you've got this file of microfilm stashed over here sompelace, why uh it's not easily controlled by a computer. And uh you know, consequently, why uh there is a lot--a lot uh there is a lot of uh resistance to its use. The uh the only justification for using microfilm is uh economic. Okay, the only justification, the only reason anybody would want to use microfilm is that you do it, I mean that you--there is virtually no better way than microfilm in that if you've got a cubic foot uh in which you'd like to store information, why, there's no way you can store more information for less money than you can on microfilm, and that, in the final analysis, is the reason uh that it's used. Okay. Microfiche--microfilm comes in uh a number of uh different forms. Six--six basic uh forms uh of the--the uh media. Uh roll film, cartridges, microfiche, jackets, aperture cards, and something called ultrafiche. And I've got examples of some of them. Okay. This is a uh okay, first of all, what's called roll film comes in two different forms. I'll talk a

little bit more about that later, but okay. This is a standard sixteen millimeter uh roll film. Okay. It looks just like movie film, just like a sixteen millimeter movie film, except there are not any sprocket holes on the edges. Other than that, it's just like--it's just like movie film. It's standard silver film. It's the same kind of film uh that you use to photograph uh, you know--to make black and white photographs of your dog or whatever. Uh okay. Cartridges. Cartridges are basically roll rilm. Cartridges are basically roll film except uh they have two--they have to have two holes, kind of like the cartridge that you have typing ribbon on or--or uh supereight cartridges. But uh basically a roll film uh can be inserted, then, inserted into a reader or pulled out--out of a reader. And uh uh it's--you don't have to string it, uh you know, onto another spool again. So it's a lot--a lot easier to work with from that put--from that point of view. Secondly, you can take it out of a--take it out of a reader and leave it where it is. You don't have to rewind it every time you take it out of a reader, and that sometimes is a significant thing uh if you're in a situation uh where you have to go back uh back and forth uh between multiple uh rolls. Okay. Microfiche. Microfiche is a French word. . . . Okay. It comes in two formats. Like many other things, there's IBM's format, and then

there's the rest of the world's format. IBM format is the same size as an IBM card. The rest of the world is this size, uh uh which is uh one thirty-five by a hundred and five millimeters or something like that, approximately four by six inches. Uh now, as I say, I-IBM has this--has this other format which they use almost exclusively. Uh okay. Jackets are a form of microfiche. Uh jackets are these--those kind of special little--pass these around, please. Uh, it's--it's a special little nylon jacket in which you can insert uh little strips of roll film. So it's, essentially, a way of making uh making a microfiche uh out of a roll.

A: . . . what form. . . .

L: Okay. It's going to come out that way in a standard--or well, it'll come out standard if it's microfiche. It depends up--it depends upon the device. Uh most devices uh come out in either in microfiche or they'll generate roll film. Okay. Uh jackets. Okay. Next thing is aperture cards. Okay. This is an example of an aperture card. An aperture card is just a standard data processing card, and it's got a little hole in which you insert a chip of microfilm--microfilm. Uh let's see here. Now they come in various formats, also. Like here's one, for example, that's uh I think, three little strips of sixteen millimeter microfilm. That's uh--

A: . . . .

L: I guess that's all. Uh okay. Finally uh we've got ultrafiche. Okay, now, ultrafiche is just microfiche, only more of it. Okay. Ultrafiche is uh ultrafiche--

A: . . . .

L: You need sharp eyes to read that microfiche. Well, you need very sharp eyes to read ultrafiche. And realize you're dealing--well, you're dealing at uh much higher reduction ratios, and it uh and uh--

A: . . . really mess. . . .

L: The scratches?

A: . . . .

L: Yeah. Well that's--it probably would. Let's uh we'll talk a little bit about that later because some kinds of films are better than others as far as scratches. Uh it doesn't look too bad to me. Usually--that's one of the things again. Uh yeah, that does look really bad.

A: . . . .

L: Just by--just playing it through the reader there, but uh that's one thing, the susceptibility to scratches. Silver film is just terribly susceptible to scratches. Whereas uh this stuff is usually not that bad. Uh can't read it anyhow. I don't know why I pass it around, but take a look at it. Uh okay. Okay. Well, we'll talk uh bef-before we uh--

A: . . . .

L: Yeah. It's like two hundred by four hundred, or something like that.

A: . . . how do. . . .

L: Hm?

A: . . . how they. . . .

L: How do they make it?

A: . . . small typewriter. . . .

L: Oh. No, no, no.

A: . . . .

L: I uh once had a professor. He said, now that we've got this microfilm, now, we're going to start uh and we had a human factors lab. So now we uh are going to work in our human factors lab and develop some really small people that could do this. No, actually what they do is they start out--they start out with a standard page. Okay. They take a thirty-five millimeter picture of the page of all those pages, and then they take another picture of the thirty-five millimeter. It's just--it's a very uh high quality resolution type thing. Okay. Uh okay. A little kind of uh basic stuff on microfilm. Okay. First of all is, there are three different kinds of film that are used when you're working with microfilm. Uh the first is a standard silver nitrate or silver halide film just in--just in-- and it's uh uh somewhat uh higher resolution film than uh than uh uh, I mean a--it's a higher speed, higher resolution film than uh than uh you would buy.

But it's basically the same kind of thing, a strip of acetate with a silver halide or silver nitrate emulsion on top of it. And that is exposed by--exposed by light. Uh uh that is the kind of film that's used, always used, for making originals, but uh uh for the first--first uh copy uh is always a silver nitrate or silver halide uh silver halide, silver film, anyway. Okay. Then there are two kinds of copies that--two kinds of copies, or two kinds of film rather, that are used for making copies. First is diazo. The second is Kalvar film. Kalvar is a trade name, but uh uh but there's only one company that makes it, and so it's a kind of uh trade name and a generic name also. Uh both uh as I say are good for making copies. Silver nitrate film is uh uh well, it has its good aspects and its bad aspects. Uh one of the good aspects is it's very fast. I mean it's like a hundred times faster. Uh you can expose it a hundred times faster than either diazo or Kalvar film. Uh uh se-secondly, uh uh it's uh reasonably permanent. Uh diazo film is reasonably, uh as I say, it's reasonably permanent, uh uh but it's not very substantial, or it doesn't stand use. It doesn't--it just doesn't stand wear and tear a lot. Uh if you put it in a safe someplace and lock it up, why it will last for a long, long time. Uh but if you use it everyday, why it just doesn't last long at all. In fact, the--the uh

emulsion on the acetate strips uh uh wears off very, very quickly, and as a practical matter, why it's not something that you can use for--for--very often. Uh di-diazo film and Kalvar film are both uh different kinds of products uh uh uh that--that have some advantages. Uh in diazo film, why there--there's a dye that's actually uh in the material--the material, diazo material. It's not like silver film where you have some kind of material that is on top of it and a sheet of acetate. In diazo film, why the--why uh the thing that gives it the--the color, the thing that gives it this--this substance is actually inside the material, and it's exposed by light--by a combination of light and--a combination of light and uh heat and ammonia. And to make a uh to make a copy out of a diazo or to uh make a diazo copy of a solar original or any kind of original, why the process you go through is basically the same. You take a blank, unexposed sheet of diazo material, diazo film, and uh put it next to a uh original. Okay. Run it through this little machine. It takes about thirty seconds. Run it through this little machine that first exposes it to uh that exposes--exposes the film with ultraviolate light, goes down a little farther and gets all heated up, and then it squirts some ammonia gas on it. It comes out the other end, and, then, like magic. Uh very cheaply, like a nickle. Uh the material costs

about a nickle, and that'll make a copy uh uh and, as I say, it's very easy. And when you get it done, I mean, when you get done with it, why, you've got a copy that--that uh is uh copied clear through. I mean, you can't scratch--you can't scratch it off. Basically, it's very impervious to just normal types of wear and tear. Right. Uh Kalvar film. I don't know very much about Kalvar film. It is not nearly as widely used as the diazo. Uh uh Kalvar film is a vesicular film. It's uh a vesicular, V-E-S--it's--it is like the stuff--have you ever seen these transparencies made?

A: . . . .

L: What makes it black? Magic?

A: . . . got to be a light. . . .

L: Well, it uh has actually a heat kind of thing also. This is--this is really a special kind of film also. And--and, although you can't see it, it's got millions of little bubbles in there. It's got millions of little bubbles. Uh you can think of it like that, millions of little bubbles, and uh when you have it against the white--a black and white original, why it makes some of the--some parts hotter than the others. Black absorbs heat, makes some parts hotter than the others, and the little bubbles explode and turn black on the inside. And that's exactly the way Kalvar film works. Uh it uh uh I mean, it's--essentially,

you've got--this material has got millions of little bubbles in it, and uh heat explodes the bubbles and uh makes uh makes the material turn black. Okay. So we've got three films: silver nitrate film almost exclusively used for originals, diazo which is a big copy film, and Kalvar, another kind of copy film. Okay. One last thing today. Okay. There are four different kinds of cameras with which you can generate microfilm. And let's see if we can find it here. Okay. First, there's a rotary camera. Rotary cameras are most used for uh by the way, here's some pictures of some cartridges. They look kind of like tape cartridges, and uh here's another one, also . . . standardized. Okay. Oops. Here is a picture of the rotary camera. Okay. Basically, it looks kind of like a copy machine or something. Uh they're widely used for uh used by banks for making copies of checks, microfilms of checks. Uh they usually have some kind of a document feeder, and that uh the technology is really good. Uh and they will--they will read in uh uh hundreds, small hundreds, couple hundreds of documents a minute. Uh and then there is uh essentially uh the--the camera and the film--the film and uh the documents that pass through the uh camera are synced. So as they pass through, the film and the document are passed through at the same rate, and it makes the photograph as it goes. Uh that's

one kind of film--one kind of camera. This is a giant. Uh the planetary camera is a--is a--just--it's a camera that has a bed on it. Uh it may be a great huge one like this one for making uh microfilm of blueprints, or it might be a little one like the kind in libraries for uh making smaller microfilms, uh microfilms of things such as books. Uh but you know, you have a bed on which you place the material to be filmed, and you have the camera up here, some kind of light source, and you generate, I mean, you place the material you want to copy on the bed. And you punch a button, and the film is made to advance. Uh the step-and-repeat camera is uh usually a planetary camera uh okay, usually for making microfiche. Uh uh and you--the uh clever thing about step-and-repeat camera is that it works like a planetary camera except uh instead of generating roll film, why uh it moves these big strips of film around so that you can generate microfiche. Okay. And then the fourth kind of device that we want to get to, that we're going to be more interested in, is uh computer output microfilmers, and we'll talk a little more about how they, in general, work also, but uh computer output--well, there--actually, there are two kinds of computer output microfilmers. I thought I might mention that. Um. Okay. Let's see here if I can find it. Okay. Okay. Here's one example of a Three-M computer output

microfilmer. And all--all that is--that is just a kind of special camera. Uh it's not unlike a rotary camera. It films the computer output, and you take the prinout from the computer. You take an output and pass it through that camera, and it films the computer output. Those are, in general, are a bummer. I mean, those are bad because the printout itself is bad from computer output. So that microfilm that you get is so bad that uh it's just a--a bummer. Uh what's also--it's a two step thing that--that uh the--well, it--it seems to me that it has both the disadvantages of most microfilm, that the stuff that you get is of poor quality, and the disadvantage of uh computer uh output because you've still got to uh you know, wait while the uh you're still delayed by the printing process, the slowest, you know, uh part of the process. The uh the other--and--and usually what we're talking about when we're talking about computer output microfilmers is a device that goes directly from the magnetic medium to uh film, and--and so there's no--there's paper--no interim paper step. And they go a lot faster, a lot faster, like ten to a hundred times as fast as the standard printer, uh and you generate the stuff. It's a lot cheaper than paper. Um so we'll talk a little bit more about that. Okay. Questions?

A: . . . you seen. . . .

L: Yeah.

A: . . . .

L: Yeah. It's good. It's good. And they do a lot but not much for--mostly for administrative stuff. But uh and there--there are a lot of things. The economics are--okay. You can store uh well, the--the economics is there for a couple of--well, a lot of things. You know, if you've got uh uh--you know, if you've got a data base that really doesn't change, only changes once a week or once a month or something like that uh why, the economics are there for generating new microfilm every week or every month rather than uh having the uh on-line storage, terminal charges, computer time, and all that's necessary to support the on-line system. Uh so there's that there for that reason. Secondly, if you've reports where there are multiple copies or where they're run--I mean, they're long and they're multiple copies. Uh uh you can really save a lot of money by generating the microfilm. Uh you can save a lot of money because uh you know, for what it costs to print a page, uh you can generate a sheet of microfilm. And that's sixty pages or something for about the same price as--as one page. If you've got to mail them someplace, you can save a lot of money. Um. Well, that's basically--

A: . . . .

L: I'm sorry, what?

A: . . . back into. . . .

L: Uh uh there--Singer uh Singer uh you know, the sewing machine company? They also make uh they also make microfilm stuff, and also they make a limited line of computer peripherals, uh and they worked and marketed a machine. I don't think they have that any more.

A: . . . .

L: 'Cause that's a good idea. That's a good idea.

A: . . . you know. . . .

L: Yeah. Well a lot depends on the data files. Uh microfilm is, in general, more permanent than uh, you know, tape for example, and it's a lot more dense uh than a tape. And uh you know, you can store it like that forever. Uh I don't think that's a technology that you can depend on. Uh it's not--it's not a bad, I mean, it's a good idea.

A: . . . .

L: Yeah. Uh yeah. I think so. Uh and uh okay. I don't know. It's kind of funny. There is uh uh well, there are two companies in the microfilm business that just dominate the industry. It's like, you know, uh IBM. If IBM doesn't do something, . . . Sperry Univac . . . cards or better . . . IBM cards for years. But because IBM wouldn't do them, why they just never did them. There are two companies in microfilm, uh Stromberg Carlson, a computer output microfilmer, and uh and uh Eastman Kodak. And maybe those companies never thought it was a good idea. So they never did it. Why,

then. . . . And uh the other thing is uh maybe they don't work. I mean, maybe on the average, why, the technology is not good enough to support that kind of thing now. So, it may be more than a political question. It may be a technical question, but, I mean, at least on that, I don't think . . . anymore. Okay. I need to go 'cause I need to go to that lecture. I hope you will come to the lecture. And I'll see you on Wednesday.

APPENDIX C
ENGINEERING 1

(L: Lecturer; A: Audience)

L: We're going to continue our discussion on linear programming today. And today we're going to look at the graphical aspects of the linear programming problem, and we are--I do all these things, and every time I do, I can't be--I keep thinking, "Why am I so good to you?" But, uh the--we're going to use the example problem that we have discussed, and one of the aspects of that problem is that it's a two dimensional problem. So all of the graphical interpretations that I'm going to show you are in two dimensions, and I will leave it to you to extend the concepts into n-dimensions. Now, there are some people who can think in n-dimensional space.

A: . . . good God. . . .

L: Uh I don't have much trouble with one dimension, and I can handle two dimensions fairly well, and uh if I really get stretched, I can think in three dimensions, but when you get over three now, I have a little bit of trouble. So we're going to uh limit our discussion to the problem that we developed last time, which was maximize the x-one plus one point five x-two, subject

to two x-one plus two x-two less than or equal to one sixty, x-one plus two x-two is less than or equal to one twenty, and four x-one plus two x-two is less than or equal to two eighty. And then, of course, we saw that x-one is greater than or equal to zero, and x-two is greater than or equal to zero. Now, first of all, we're going to uh look at the graphical interpretation of the problem. And we're going to start looking at the constraints, and we are going to start--or we're going to do all of this in the two dimensional space, the x-one, x-two space, and we will need to go up a hundred and twenty, x-one dimension, and to one forty in the x-two dimension. Okay. So this is the x-one, x-two space, and this is the space in which we are going to plot our objective function, and uh also interpret our objective function. Now the uh space that we're talking about here is called solution space because we're going to be looking for solutions in this space, and any solution to this problem is uh a pair of values, one for x-one and one for x-two. So any pair of values x-one and x-two is a solution. They're not all going to be feasible solutions, as we can see, but any pair of values is a solution. Uh a feasible solution is a pair of values uh x-one and x-two which satisfies--pair, I guess pair satisfies--satisfies all of the constraints. So, for example, a solution x-one equals fifty, x-two

equals minus a hundred is not a feasible solution because it violates one of our constraints, and that is that x-two has to be greater or equal to zero. So, it is a solution, but it is not a feasible solution. And now we're going to go through the development of the rest of our uh feasible solution space. Okay, now, really I could have drawn all four quadrants uh of this x-one, x-two space, but we can see that x-one has to be greater than zero. So we have to fall out on this side of the x-two line. So we can--anything to the left of this axis is not a feasible solution, and, by the same token, uh x-two has to be greater than or equal to zero. So we can eliminate any of the values down here. So we--our--our uh feasible solution space is uh in the quadrant that I have uh put up here, the positive--the positive values of x-one and x-two. Okay. Now let's look at the first constraint. Uh two x-one plus two x-two is less than or equal to one sixty. Okay, well, that is two x-one plus two x-two is less than or equal to one sixty. So, therefore, this uh would correspond to the line x-uh-one plus x-two is less than or equal to eighty. And we can plot this line, and uh the intercept on x-two is going to be at eighty, right here, and it will run down here to eighty. So, if we put in this line, which is x-one plus x-two equals eighty, our solution has to be less than or equal to eighty.

So that means that our solution has to be on the underside of this line, and, therefore, we can eliminate the outside of this line. So, now, our solution space, when we only look at one of our constraints--well, I guess we're really looking at--at uh three, the--the nonnegativity constraints and one of our regular constraints--is this triangular area. So all values of x-one and x-two, all pairs of these values, would have to fall uh within that space. Okay, now we can look at another one of our constraints, x-one plus two x-two less than or equal to one twenty, and that will uh intercept at x-one equals one twenty and x-two equals sixty. So it will be right about here, down to here, and put in this line, and again our solution has to be on the underside because it is less than or equal to these values. So now we can eliminate from our consideration the area on the upper side of this line. So our solution--solution space at the moment consits of this uh four-sided area uh which is on the underside of these lines. Now, our third uh operational constraint is four x-one plus two x-two less than or equal to two eighty. And this corresponds to two x-one plus x-two less than or equal to one forty and the intercept points are going to be at x-one equals seventy, right here, I would say, and one twenty. Okay, and uh the other one is x-two equals one forty which would be up here. So if we draw in this

line--have to be a little bit careful here where they intercept.

A: You're cheating. . . .

L: Uh so now the--the uh uh this constraint says that the solution has to be less than this line or in the--the lower left-hand side. So we eliminate this amount of our solution space, and when we get down here, we eliminate this little triangular. So our solution space, now, consists of this five-sided--the area inside this five-sided figure. Now this area then is the feasible solution space. So every pair of values, x-one and x-two, that we select, in order to be a feasible solution and satisfy all of these constraints, has to lie either on the boundary of this space or within the space. Now, are there any questions on the development of our feasible solution space? Every feasible solution has to lie within this area, and it can also lie on the lines themselves. In fact, we're going to find that it--the solutions that we're looking for are going to lie on the line. Okay, now, to go back to our uh to go back to our original problem, the first constraint was the constraint on department A, the time available in department A. The second one was the constraint on department B, and the third constraint was a constraint on department C. And let me just put in the equations of these lines. Uh this one is four x-one plus two x-two uh equals two eighty,

and this would be department C. Uh this one is two x-one plus two x-two equals one sixty, which is department A. And uh the--this line here is x-one plus two x-two equals uh one twenty. And this is department B. Now if we--are there any questions on this? Trying to relate it back to our original problem. Okay, now if we look for a moment at our department B constraint, the line that we have here corresponds to x-one plus x-two equals one twenty. So what that means is if our solution falls on this line, anywhere on this line, that department B would be operating at its capacity because we're using all of the time that is available on department B. If our solution falls below that line, for example down in here somewhere, it means that that department would not be operating at its capacity, and it would have some extra time, or slack time, left over. All right, if our solution falls on any line, it means that that constraint is critical, and if it falls uh if it does not fall on that line, the constraint is not critical. Everybody see that?

A: Say that one more time.

L: If--if the solution falls on a line that corresponds with a--corresponds to a particular constraint, it means that constraint is critical and that there is no extra capacity associated with that constraint. If the solution falls off that line, then that constraint

is not critical, and the--there would be additional capacity associated with that constraint. Now in uh okay. Now, we're going to look at a uh we're going to look at the objective function now. And we're also going to have the same uh space, x-one, x-two space, and I'm going to draw this uh not on the same drawing for the moment just to show you how the objective function operates, and then we will plot it on this uh on our original drawing. But our objective function is maximize uh x-one plus one point five x-two. Okay, now, what this is is if--if we had x-one plus one point five x-two equals uh fifteen, we would have a very specific line. Or if we had x-one plus one point five x-two equals one point five, we would have a very specific line. But, as we stated here, we have a family of lines. And I'm going to plot uh five, ten, fifteen--plot uh x-one plus one point five x-two equals fifteen. So that would intersect at this point, and x-two equals ten. So this one corresponds to x-one plus one point five x-two equals fifteen. We plot the one point fives in here and intersect at one and one point five, and we'll have a line going this--this way. Uh x-one plus one point five x-two equals one point five. So what we have, if I had drawn this a little more accurately, we have a family of lines. Our solution is really a family of lines. The--the constraint establishes the slope of the line.

The original formulation establishes the slope of the line, and we really end up--we have a family of--of lines. Now, since our objective is to maximize this value, and we can see if--if the--the line that uh goes through the zero point is x-one plus one point five x-two equals zero. We've started with zero here. This is one point five. This is fifteen. So we can see that in order to maximize this line, what we're really doing is moving it out in this direction, to maximize. To maximize, we want to take this line and move it as far out this way as we can. So that's what we're doing with our objective function. Now, does everybody see what we're doing there? To maximize, we would be moving it out this way. If we were minimizing 'em, we would be moving it as far as we can in this direction. Now, so far we have looked at our constraints, and we have looked at our objective function, but we have looked at them independently. Now, we're going to take a look at our objective function in terms of our solution space over here. And we're going to just--just try to visualize uh the linear programming problem in terms of these uh in terms of this space. Now uh we can plot one of our lines here. X-one plus one point five x-two equals zero would go through zero point. X-one plus one point five x-two equals zero. Now again, in this space we want to continue to move out as far as we can here, get this--the right solution.

A: . . . .

L: But we want to move our--our solution out as far as we can and still have it intersecting our solution space, our feasible space. Now, this brings up a very important property of the linear programming solution. First of all, how many solutions are there in this solution space?

A: . . . maximal or. . . .

L: How many--how many feasible solutions are there in the solution space?

A: . . . a lot. . . .

L: A lot. That's right, a whole lot. There's an infinite number of solutions. Well one of the properties is that the uh the solution will fall on the boundary of the solution space. Now, how many feasible solutions are there on the boundary of the solution space?

A: . . . .

L: We've already eliminated at least an integer--an infinite number on the inside.

A: . . . .

L: What?

A: . . . .

L: No, no, no. We still have an infinite number because there's an infinite number of points that are on these lines. So we would hope that we could come up with some sort of a solution technique that would not require

that we evaluate an infinite number of solutions. Well, fortunately, another one of the properties of the--the linear programming solution is that each of our solutions is going to fall on a corner point, each of the solutions that we evaluate at least. So uh the optimal solution which, of course, is the best solution, is the one we're looking for, uh will always be at a corner point. So uh each--so in--in solving the problem, it is necessary uh to look at only corner points. Since we know that our optimal solution is going to be at a corner point, then we only have to evaluate the corner points. Now this is a very important property because it--when we start limiting ourselves to corner points, all of a sudden we have a finite number of--of points to look at. We started off with an infinite number. We reduced it to an infinite number when we uh said we only had to be on the lines, but, now, we have a finite number. So in our--in our particular problem, there are one, two, three, four, five corner points. Those are the only points that we have to evaluate, and we know that our optimal solution is going to be at one of those corner points. So now the problem is to move our solution line as far out in this space as we can move it and still have it intersect in one of these corner points. So we're maximizing it by moving it in this direction, but it still has to hit one of the--one of the extreme points,

the extreme corner point of our feasible solution space. Now I will simply state that when we get into more than two dimensions, these same uh concepts apply. Uh they get a little bit more difficult to visualize. But we're doing exactly the same thing, except we are replacing lines with planes. And in some cases, we're replacing them with n-dimensional planes. So, in any case, try to visualize it in two dimensions, and take my word for the fact that the same uh principles apply in more than two dimensions. Now, are there any questions on--on this--on this particular uh the development that we've gone through here? Okay, well, let's look at an example then. We're going to follow through the example that we had when we--when we developed the mathematical solution, but we're going to work another one here, and this is maximize our objective function which is three x-one plus two x-two, subject to x-one plus x-two less than or equal to twenty, x-one less than or equal to forty-five, and minus three x-one plus five x-two less than or equal to sixty. Okay. Again we have a two dimensional problem. X-one is on the--this axis, x-two is on this one. And, okay now, let's put the constraints on here. First of all, we have one x-one plus x-two is less than or equal to twenty. So the line that we want to plot then is x-one plus x-two equals twenty for constraint one, and that is going to be a line as such. That is

constraint one. Okay, constraint two says that--and--and uh our solution has to be less than or equal to twenty. So we're on the underside of it. So again, if we cross out our negative areas, we are limited to our uh positive quadrant. The first constraint says that we have to lie less than or equal to this line. So we now have at least a bounded solution space. Uh the second constraint says that x-one is less than or equal to fifteen. So we will plot x-one equals fifteen, and that will correspond to this line, x-one equals fifteen. And since we have to be less than or equal to that, we're on the left-hand side. So again, we eliminate the nonfeasible area. The next constraint, x-one plus three x-two is less than or equal to fifteen. Uh x-one plus three x-two equals--excuse me, forty-five, and this will--where do I plot this thing?

A: . . . .

L: Okay, this goes from fifteen--from uh x-two equals fifteen to x-one equals forty-five, which is out here. So, this one is x-one plus three x-two equals forty-five, and we have to be less than or equal to that. So we eliminate the area above the line, and our solution space is again uh reduced. Now, we have minus three x-one plus five x-two equals sixty, and the intersect points are going to be x-one equals minus twenty and x-two equals uh twelve. So x-two will be twelve, and x-one is minus twenty, which is back here. It goes out

this way. So this is uh minus three x-one plus five x-two equals sixty, and we have to be on the underside of this. So again, we eliminate this area, and this is our solution space, our feasible solution space. Now again, because of the--the uh property that we went over before, we know that our--our optimal solution is going to be at one of these corner points. And we have one, two, three, four, five, six corner points. Our uh objective function, three x-one plus two x-two, is going to be a line that is sloped like this. This is uh three x-one plus two x-two equals zero, and we have to move this out in this direction. If we check this corner point here, we will get three x-one plus two x-two equals--well, this intersects x-two equals zero. Uh yeah, x-one equals zero, and this will intersect at this point which is twelve. So x-two equals twelve. So this would be twenty-four. This is x-one equals zero, x-two equals twelve. We can plot the line through this point. This is going to be three x-one plus two x-two equals something, and this is going to be at x-one equals fifteen, x-two equals zero. So this is going to be forty-five. So we've got a better solution. We're moving toward a better solution. Now, it's not getting any easier here. We can try this point. It's going to be our--here's going to be three x-one plus two x-two equals something, and this intersection point--how do we find the values of x-one and x-two at that intersection point?

A: . . . two equations. . . .

L: Right, we have two equations and two unknowns. Uh the equations are--at this point uh if we have x-one plus two--excuse me. X-one plus x-two equals twenty, and we also have x-one equals fifteen. So that gives us x-one equals fifteen. Uh x-two, then, is going to be five. So the value of our solution then is forty-five plus ten is fifty-five. So we are, again, better. That is the optimal solution, but just to prove it, we're going to check the value of our solution line at this point, and that point is going to be the intersection of uh x-one plus three x-two equals forty-five, and the other line that goes through there is x-one plus x-two equals twenty. Now if we subtract these, we get two x-two equals uh twenty-five, or x-two equals uh twelve point five, and x-one, then, will equal seven point five. So our solution Z equals uh three x-one plus two x-two is going to equal uh three times seven point five plus two times twelve point five, and this is twenty-two point five plus twenty-five, and this is forty-seven point five, which is less than the value that we obtained at this point. So by trial and error, we have determined that our optimal solution point is at this point, and we found that the--therefore, that the optimal solution is x-one equals fifteen, x-two equals five, and the Z for that equals fifty-five. Yes.

A: . . . .

L: What I did is I just put the line through this corner point. We--we know, what I've done is I've evaluated several corner points. By inspecting the slope, we--I eliminated this point here, and we just kept moving on. We evaluated this corner point, this corner point, this corner point, this corner point, and this corner point. And the first one here, of course, at--at this point we have x-one equals zero, x-two equals zero, and, therefore, our objective function is going to be zero.

A: . . . .

L: Okay? We are going to develop a mathematical procedure that will systematically lead us from one corner point to another. So you will not--what I'm trying to develop now is that you will understand the--physically what is going on and graphically what is going on when we solve the problem, but we're going to be looking at a mathematical technique that will start us off at one of these points and will move us to an--an adjacent corner point, and it will always move us toward an optimal solution. In other words, we would never go from this value to this one over here. This has a--our solution has a value of zero here. The value of our solution over here is forty-five. Well, we would never go back to this one which is twenty-four. You're always stepping toward the optimal solution. And the only time it gets hung up is sometimes if it falls on a line. For example, if these two values have

the same value, it--it may try to oscillate between the two, but there are procedures for getting around that, but that's a little bit above the scope of this class, except the fact that there are techniques of doing it. Are there any more questions on the uh the graphical interpretation of the linear programming problem? Well, the--the next period or so, we're going to, then, relate the mathematics to the uh graphical interpretation.

A: . . . class Friday. . . .

L: Yes.

A: . . . .

L: Next Friday we don't have class.

APPENDIX D
ENGINEERING 2

(L: Lecturer; A: Audience)

L: Well, let's get started. I was talking last time about the indirect tensile test. In fact, we performed a couple tests and obtained data for one sample which was tested probably at a temperature of around seventy-five degrees farenheit. The information I provided on this sheet will give you a brief rundown on elastic theory and the hypothetical stresses that you get with respect to ring or hoop stresses in a specimen that is tested in this fashion. So, if you start out at the top, you'll note that we define this test as an indirect tensile test. I would say that this is probably the most accepted terminology, although some people will call it a diametral test. And in fact, when you perform dynamic test where you're using repeated loadings, the diametral test uh is quite often--or is referred to as diametral in that case quite often. If you draw a similarity between this test and what is used in concrete, you'll find that in concrete we call it the splitting cylinder test. So you have approximately three names for the same test. Just keep that in mind. In this case, I'm dealing primarily with

a standard pill, or sample--test sample, four inches in diameter and two and a half inches in thickness. And you note--you'll note on the diagram that I put in one and a half inches for the minimum dimension. The reason for this is that the . . . do probably constitute uh a--a discontinuity as far as their stress patterns. And if you get the specimen too small, it's possible that you're going to have trouble loading it in a truly diametral mold. I have tested specimens as thin as one inch--

A: Asphalt?

L: Asphalt concrete specimens. And I find that it's very difficult, except in a few cases, to get good results. If you have an inch and a quarter, an inch and a half, you're in good shape. And you can test specimens that are even longer. The only difficulty is if you get too long, then you have to worry about the positioning of the spe-specimen and the potential for nonuniform loading or stress concentrations, in other words, an excentric loading. And the device we have downstairs is pretty much self-centering, as long as you put it in properly. You'll notice in the diagram that we can have one-half inch wide loading strips. Those strips are actually curved to conform to a four inch diameter specimen and the sharp edges on the curved strip rounded off so it doesn't dig into the specimen. In some cases, they will actually put a thin rubber

membrane along that strip to cushion it even further. If you're testing concrete, normally you use just a flat--or a flat surface as a point contact, but you eliminate, again, stress concentrations due to nonuniform loading. You normally use something like one-eighth inch piece of--of uh wood of maybe an inch wide. In other words, it's a cushion block. The diagram illustrates the diametral measurements using LVDT's, where you're measuring the horizontal deformation or what we might term in some cases, if we're looking at elastic properties, the elastic deformation. The distribution that you see in the sample here, the stress or strain distribution, assumes that it is an elastic material. So that your stresses and strains would be proportional. With bituminous materials, if you were testing for uh even short periods of time and running the stresses up fairly high, you're going to find that you will have some creep. So that creep is occurring, and there's no way that you can get around that. In the case of the dynamic test, we keep the stress at very low level. And just to illustrate this, let's say this is our time or number of cycles that we're looking at, and we're looking now at the uh deformation response. I'll just put delta there. If we see this type of response, woop--let--let me put in zero up here. I'll make this zero deformation. If we see this type of response as

we load it, and this is a haversine loading. I'm not talking about a reverse loading, because we put the load on only in one mode, we can't pull it back. What we're going to find is that we'll go along like this. Here's our haversine loading. Here's a rest period between loads. And if we can continue loading at that stress level without any permanent deformation occurring--in other words, this remains constant. It always comes to zero--we have what we can consider as being true elastic response. Now what normally happens, though, is that this, unless it's very cold temperature, will end up on a slope. So that as we're testing, it looks like this. In other words, every loading cycle is coming up in this fashion. And looking at more detail with respect to that loading cycle, what you'll find also is that you have this condition. Okay, and then we go into the next loading cycle. And you notice that I've illustrated this as having a nonuniform curve condition, which indicates what? It indicates that if I look at the same time interval here, come out in here somewhere, I should be back at zero, shouldn't I? Well, what--what this indicates really is some delayed elastic recovery. All right, is this--is this really total elasticity? This is the question. It may be delayed elastic effects or whatever. At any rate, some people will take the deformation or the strain as being the mag--woop-let me change that.

I put that on. After all this is on straight chart paper, and it's going up in this fashion. We'll take that value right there as being the magnitude of the strain in order to compute the modulus of the material or the resilient modulus. In other cases, what they will do is take the total value. In other words, if I came up here and drew a line in parallel, I can take the magnitude of that and use that strain to compute a modulus. And you see--can see automatically that if you do this, you're going to end up with two entirely different values. Plus, most people are neglecting the fact that we have accumulated dynamic creep that is occurring over a period of time. Now, to what extent does this affect the results? If we ran a conventional fatigue test, you would find that if we allow the recovery time here to be sufficiently long, such that we would always recover back to this line completely, it would in fact change the slope of this line, and we would end up with less dynamic creep, what appears to be dynamic creep. To what degree, that's again dependent on the condition. But the point I want to make is that the dyn-dynamic creep that we measure here, if combined with uh the delayed elasticity, is very difficult to separate out. If you're running a constant stress test, you can do this because you let it recover. You know our standard creep curve? You just let it recover. When it gets out there

reasonably flat, you've probably recovered the majority of our delayed elasticity. If this was a fairly brittle material with very little creep, then even though we have a slight slope here, the response that we measure would probably be the true elastic strain. But there's some problems with this type of test because you have to look at it in the proper light, and you have to analyze it properly. Did you have a question?

A: Two questions. Can you--well, first of all, what's the time between the repeated stresses?

L: Well, conventionally, quite often they're using this time period here. From loading to unload is one-tenth of a second. And then you might have zero point four second for the uh rest time.

A: . . . when they do this, do they set up. . . .

L: All right. I--what I talk about is the dynamic test here. They set it up the same way.

A: . . . actually. . . .

L: That's right.

A: . . . plot so that. . . .

L: Yes.

A: . . . plot that curve. . . .

L: You do--you do it exaclty the same way except for the dynamic mold, and so you'd be getting the cyclic uh stress and strain values as you're going along.

A: And if you. . . .

L: Gradually increase.

A: Increase. . . .

L: Right. Now in the test that we performed, you can see that we have an entirely different arrangement becuase we provided--performed a static uh test where we increased at a fixed strain rate or deformation rate. Uh we took the stress right up to failure. So now the response that you get there is going to look a little bit different. And you remember what it looked like on the paper, but if I take--take the loading curve, had let's take this stress. We may see just a slight bit of seating here. And then, if this is a fairly brittle sample, it will go up, fairly linearly, and then drop off abruptly. Well, this might actually be a point like--looks like that, almost. It's highly elastic. It's a brittle elastic material. When it's ductile, what does it look like? It looks more like that, indicating it's very difficult to establish anything that has a semblance of a modulus there. Okay. So you're looking at this. Do you want to take a tangent modulus at this point? Do you want to average it out at the peak loading, or what do you want to do? And your strain response is going to be similar. It'll be somewhat linear here, and over here your strain response will be nonlinear because what you're looking at is the combined effect of both elastic and creep. Now, you can term this as stiffness. And so, if we took the total strain at any time, or in

this case, under this type of loading condition, I could call it the stiffness of the material, but it's not defined, you see. You remember how we were talking about defining stiffness? So that you have it according to a specific stress, a specific time, and temperature. That's the only way you can define stiffness.

A: . . . seems to be very important. . . .

L: Well, it's always important.

A: . . . same material could give you. . . .

L: It's just different temperatures. Or two different materials could give you the same shaped curve if they happen to have the same viscosity. And remember the same viscosity is dependent upon the shear rate or the strain rate to which you're subjecting the sample because of the shear susceptibility factor. Yes?

A: . . . so when. . . .

L: It would be the, as far as I'm concerned, if you measure it properly, I would say that you have the same thing as a modulus of elasticity.

A: . . . elastic material. . . .

L: It's elastic material. Right. That's true.

A: . . . elastic material. . . .

L: Then it's time dependent.

A: . . . .

L: And the time of loading is going to affect whether you have a modulus or whether you have a--a resilient

modulus. All right. You see my point? If I keep the time of loading very short, it doesn't allow--and then the stress level is low, it doesn't allow time for--

A: Creep.

L: creep to occur. Consequently, I get a resilient modulus and a dynamic modulus that are the same.

A: Yeah.

L: Let me illustrate that point. Remember when we were saying--well, let's look at the modulus over here, and I illustrated, I think, two different conditions. One was the dynamic modulus here where we're talking about the repeated loading effect. And down here, we can call this a static modulus. We can call it stiffness of the same kind or whatever. This--or I should say, both of these values will be equivalent when the material gets down to very high--or up to a very high viscosity. In other words, becomes more of a brittle elastic material. As you see, our difficulty when you talk about fatigue, fatigue concepts, is always recognize the fact that the time loading and the rest period between affects the results. Okay. So they've never rationalized this. They say that, well, this is an effect. But they turn around and then they are trying to simulate the life of this pavement based upon the repeated loads in the laboratory, and they find that it doesn't match with what they have in the field. And this is one of the problems. The other

problem is, of course, that in the field you have a little bit different condition. You also have an elastic support medium that is bringing this back into position.

A: . . . random loading. . . .

L: You don't have continuous loading, correct. So there's a variety of differences, and if we refer to this particular diagram here, what you're looking at here is the stress distribution, the horizontal stress distribution across the horizontal axis of this sample. It could be a strain distribution as well. And, remember what I said last time about whether it's shear susceptible or not. Because if we have any form of creep involved, if it's Newtonian, the creep behavior will be proportional to the stress. So if we had a strain distribution, total strain, it would look like this. Then if we could take out the creep strain, we would be left with the elastic strain. Recall what I have said now. Here's our strain distribution due to some stress. If creep is proportional to stress, then in this sample, I'll get some creep, and then what is my elastic strain? It's like this.

A: Can I ask a question?

L: Yes.

A: Did I understand you to say. . . .

L: All right. That's only in a particular case. If--if if this is not Newtonian, if this happens to be a shear

susceptible material like a roofing asphalt--

A: . . . I mean. . . .

L: Now, let me do it this way.

A: Okay.

L: I'll draw in this little distribution right here. The rest of this is elastic strain. Only when the stress is sufficiently high in the time period that we're testing do we develop creep strain, and that was in the central portion of the sample--

A: . . . .

L: Non-Newtonian, highly shear susceptible material. Therefore, when we look and measure this strain, that strain will be approximately equal to the deformation that we're going to measure out here. In the other cases, that's not true. So you have some real problems in analyzing these tests, and people use the indirect tensile test almost indiscriminantly to define the response of these materials. They really don't understand the influence of the specimen. There's another little interesting thing about this when you talk about creep re--er not creep recovery, the recovery of your delayed elastic effect. You get delayed elastic strain recovery. Here, depending upon the level of elasticity you have, you can see that if I stop the testing soon enough, I'm going to get a lot of recovery. In other words, I can put a pretty high stress on that, for a short period of time, and when I

take that load off, the proportion of recovery is going to be much higher than when we talked about this Newtonian-like material, okay? And, secondly, out here, if we do have some shear susceptibi-susceptible asphalt, the fact that we haven't developed much creep in these zones, that's--this is like a hoop, it means that we'll recover the elastic strain. The delayed elastic strain will recover faster, and as that wants to recover, what is it tending to do to the sample? Pull it back together. So you have the effect of the geometry of the test. I think that it's affecting the overall resopnse. So what we've done, by the way, what we've done is just put in an SR-four gage in here, and say this is the measured response along the failure plane. This is the strain that's involved. If our stress computation is correct, we can compute the modulus in the conventional fashion with the stress over strain, not using the elastic equation. This seems to work reasonably well. At least it gives us values that appear to be reasonable.

A: . . . this all. . . .

L: Oh, we've--we've done this. We've done this, but not for estimating life of the pavement. All we have found is that if you know the asphalt viscosity, and density of that material is similar to the density or air void content of mixtures in the laboratory, that, in fact, that core out of the pavement will perform the same way

as the sample in the laboratory. Now, normally, you'd have a harder asphalt, but it all works out. If you were to test at a different temperature, where you have the same viscosity for that laboratory prepared specimen, the same viscosity as in the field, you'll find that you get the same basic response, unless the field core is so hard that you've initiated some kind of brittle fracture, and, consequently, there your stress levels will be lower. You get earlier failure. So from the stand--from the standpoint of projecting ahead and determining the life of the pavement, no, we haven't done this, although we have approached it from the computer simulation and to basically establish the critical condition under which this pavement would fail. What we're really saying is that we may go one year and have failure in wintertime. We may go ten years before we have a critical condition which includes the fact that the temperature was extremely low or the asphalt has age-hardened sufficiently. So, with respect to time, in years, let's put in here uh failure potential. If we're looking at failure potential, what I'm really saying is here's where it's going to fail. This is our failure criteria. Now, combining temperature effects, combining the effects of--of wheel loadings, for instance, what if you run a truck that happens to be overloaded at this critical time period? It can crack up the pavement or initiate crack-up. Combining the

fact that you have age-hardening, you know, with time the asphalt viscosity is increasing. It means that we may be operating somewhere in here, and all at one we get those critical conditions that put us up to failure at this point, or if it was due to age-hardening, what would you anticipate? You'd anticipate something like this maybe, and you'd have failure up here.

A: . . . looks. . . .

L: In this sense, they're not. What they've been trying to do is use the fatigue concept, where, they say, we apply so many equivalent eighteen kip wheel loads over the life of this pavement. They're accumulating in some fashion, or projecting ahead, or we're taking past experience where we accumulated so many, and when it gets up to this point, we have uh some cracking, failure. And we say, well, now, cracking was initiated at this particular time after so many equivalent wheel loads. And this is now the criteria that we try to relate back with any physical testing we do in the laboratory. Unfortunately, they forget about the asphalt viscosity, and the people who are testing in the laboratory will be testing with one asphalt. People evaluating field performances use entirely different asphalt, and they don't uh link the two. So fatigue concept--what I'm saying is fatigue concept is not made for asphalt concrete materials. It's not valid. It's not a good way to go. Go with the

critical concept, where everything becomes critical. If you're up north, and have freeze-thaw action in springtime, the subgrade thaws out, low subgrade support. The pavement is still cold, brittle. Your potential for cracking is increased tremendously, and this is a critical condition if you can model it properly. And you have design techniques, pavement analysis uh methods and that, whereby you can do this, but they haven't for the most part done that. Florida is the only place that's been playing this--that's going in this direction at all, which is surprising because Florida is not a cold climate. Uh but the other reason is--is that Florida--here pavement failures are due to failure of the asphalt and not due to limerock base or subgrade or magnum materials for the most part. Okay. Quickly. I want to move along here. Looking to the right, you'll notice that there's a little diagram which illustrates compressive stresses as we come--look down on the verticle axis on the specimen, compressive stresses and goes into fairly uniform tensile stresses. The computation for those stresses is given below which is based upon elastic theory, that two p pi LD. You have equations given for the modulus and for your strain. And, by the way, here that strain is your total strain which will be E sub-X or epsilon sub-X, epsilon sub-E. That's basically your total strain in this specimen. And

when I say total strain, I mean uh strain being produced uh through this specimen in the critical strain, basically your maximum strain. That's what I'm trying to say. And then, below, we have another equation which relates the modulus to both the strain and the stress that's being applied. And you'll notice that we have one plus three mu. If you use this equation for concrete, you'll find that it works very nicely. Using the asphalt materials as I mentioned before, it's going to give you values that can be extremely high. And the reason for that is those values, just like the dynamic, aren't down in here. They're going to uh be peak value which, by the way, levels off. It levels off by the time you get up somewhere around the vicinity of, oh, E--E mi--E thirteen pascals, something of that order. This is uh extremely high modulus value. In other words, you're talking about one and a half, uh I think, one and a half million or more. So we're--we're getting or approaching the value that's comparable to Portland cement concrete. Also listed below there is the typical value that is normally used for Poisson's ratio, point three five when you're dealing with asphalt concrete materials. And to measure Poisson's ratio, some people claim they can do it. I personally have tried it, and we end up with values that float around quite a bit. I believe that it's very difficult

to establish Poisson's ratio when you're going to end up with a deposit of elastic--elastic response as well as creep. It's strictly elastic response, hardly any creep. I think that you could probably use the point three five with reasonable confidence.

A: . . . was an issue. . . .

L: No one has done this as yet. All this--the best information on Poisson's ratio was developed by Schmidt with Chevron in California. And he determined that although there was some variation in his data, you could select the point three five and end up with almost the same results. Remember the Poisson ratio doesn't make a major different although it is multiplied by a factor of three in this case. Now, don't forget when I talk about the type of test that we've done using the strain gage that we throw this out the window. And we are using nothing more than sigma X divided by the uh strain, epsilon X, and determine modulus which gives us lower moduli at the higher temperature. When you get real cold, you'll find that those moduli will then tend to merge. It becomes very brittle elastic. Yes?

A: . . . the denominator. . . .

L: Oh, that's L delta E.

A: L delta E?

L: That's--that's the length of your specimen uh times the elastic deformation which you've measured with the

LVDT's. That sometimes is written as delta H, which I dislike because delta H could include measurable creep, which you could differentiate between the creep and the elastic response depending upon how you go at it. Okay. If you run the indirect tensile test in quick bowl like we did downstairs, there's no way in the world that you can uh differentiate creep from the elastic response. Consequently, if you put in the total deformation, you're going to end up with a modulus which is more like a stiffness, and that isn't even correct. Yes?

A: . . . where did we use this. . . .

L: You haven't used the modulus before.

A: We haven't?

L: No. You--we've computed the shear modulus, G-one, for the asphalt, but we have not computed the modulus for the asphalt concrete.

A: . . . where are we. . . .

L: All right. This would be--if you were determining the correct modulus, this would then go into multilayer program where you have a pavement system with probably two or more layers. Let's just make it a three layer system. This would be base. This is your asphalt concrete, and here's your subgrade. Well, I'll just leave that out, subgrade. So what we call this is E-one, E-two, E-three. If this was a suitable measure from our indirect tensile test, then you would go

directly into this pavement analysis system here. If we were to evaluate the base force, we might use for instance the resilient uh modulus test for granular materials over the subgrade so that we could actually do this in the laboratory. The question is whether or not we're getting the proper measurement of elastic response. In other words, is this modulus correct as it relates to the field? Can we duplicate its response characteristics? Let me illustrate that. If I was to go out and put a wheel load on here, measure the deflection basin, measure strain from the surface or whatever, all of those measured values should correspond to the computer predicted value using multilayer elastic theory. If it doesn't compare, then it means either our theory is no good, or the moduli that we put in there do not define modulus conditions being placed.

A: . . . compared. . . .

L: Oh, in the laboratory, they jibe.

A: . . . jibe. . . .

L: Now, to what degree they--they jibe in the field with actual pavement response, uh some of it looks good. And then there's some places that maybe it's questionable. Same--the same thing is true of uh asp--Portland cement concrete pavements. Okay. Yes?

A: . . . this equation. . . .

L: Right. Right. If you want this, this would be in psi. Those dimensions would all be in pounds and inches. Yes?

A: . . . same equation. . . .

L: That would be true. That's what you'd want to do. So when you have a curve that looks like this, this is your elastic resonse, right here, isn't it? This that you're accumulating with time is your creep or nonrecoverable, permanent defor-deformation, whatever. So this is what you would be using in order to make that computation. Okay. Any other questions? Let's leave the indirect tensile test and move on to some slides. And I want to now start talking about pavement systems. And let me just briefly comment before we start with the slides what pavement systems we're dealing with. Generally speaking, we can have what we call full depth. A full depth asphalt concrete pavement is one in which your total structural layer is asphaltic concrete, and that is placed directly on a subgrade. In Florida, there might be some merits to this, other than the fact that we have some cheap material which is limerock, or relatively cheap. And it's probably more economical to put a limerock base in place of some of this asphalt rather than go into the full depth. The first approach to full depth, ironically, was in Woodbridge, New Jersey. A fellow by the name of Beagle had two things that he was

interested in. First of all, he had a moisture problem. And so granular materials accumulated moisture, and frost heave problem. And loss of subgrade support because of accumulation of moisture on those clays was really plaguing their street system. So, what he decided to do was look at this business of full depth. But he also thought, well, we have a problem with respect to getting in and getting out of--of these areas, the various streets. And as for the public, uh traf--the transportation system isn't dis-disrupted for any length of time. So he then also went into deep or thick lift construction. Now, thick lift construction in his approach was to put it down all in one shot, other than the wearing surface. So, he's putting down an asphalt concrete base that went up to as thick as about eighteen inches, I believe, and the fact that it was eighteen inches--they had to run a bulldozer over it to compact initially, and they they ran their uh compacting equipment. And they found that with the thick lifts that they actually had better compaction, lower air voids, a better pavement. Now, before that, you couldn't convince anyone. You could tell 'em, "Shoot. Put it down thicker. You can do it." Nobody'd believe it.

A: . . . cost more. . . .

L: What? No, not really. Actually, in his case it comes out cheaper. So at the current time, I think their

standard now is somewhere around eight inches or nine inches of full depth, one width plus a wearing surface. This is a concept that was developed and the Asphalt Institute obvious--for obvious reasons has promoted this. Other typical sections might look like what we just described before where we put--uh let's say we take the Florida primary system. Four inches of hot asphalt concrete, ten inches of limerock base, and then down here we have our subgrade. In some of the older systems, we might have added another layer. And let's just throw in some layers here now. This is crushed stone. Here is your asphalt concrete. Down here you have a subbase, and then you subgrade. The advantage is that the subbase can be constructed of materials that are lower in quality, maybe some natural materials, a clay uh gravelly uh sandy type of material which will compact readily, whatever. It may not have the strength of the crushed stone base, but it--it allows you to build up here over a weak subgrade. Now if you, obviously, if you have a high, really good subgrade materials, which are out there on the terrace with good gravels, it seems kind of ridiculous to come in and put in a weak subbase. You would obviously uh come in and put in good crushed stone base and follow that up with uh your asphalt tile. There's a lot of variations. There's also another variation that we use which we term--and now this is more from rejuvenating pavements

or bring--or I shouldn't say rejuvenating, from the standpoint of rehabilitating pavements. When you want to put an overlay on another pavement, it becomes cracked. How do you eliminate the reflex cracks from going through? Years ago, Michigan said they solved the reflex cracking problem. I think that was over concrete. They put eight inches of asphaltic concrete on top. Well, that's solving it, but it's very expensive. On flexible pavements, we can still have the problem. So if this is cracked, you have two laternatives. You have the laternative of removing it by recycling, making a better pavement, hopefully, or by putting on a stress relief layer. And that stress relief layer is usually large aggregate part-particles, open grade, high in asphalt content, or a rubber asphalt membrane uh maybe that's uh three eighths or a half inch in thickness, which allows for great strain tolerance. It means that when the crack here-when things start moving, it absorbs the energy, dissipates it before it gets to the pavement so that you prevent cracking. Another way is to reinforce it. And so, instead of using a stress relief layer, you can come in here and put down something like Petromat fibers, or fabrics. The fabric is a structural material like the fiberglass cloth or something along this line. Put it down with asphalt, and now it tends to hold things together at that point. The only joke is--is that

there's some cases where you get enough movement that you actually fracture the fiber. So it is not necessarily a total--uh let's say a totally adequate system. Well, let's just review a few other bits of terminology.

A: . . . .

L: Well, full depth is just all aslphalt and compacted subgrade, that's all. Where--where does the prime coat go? This is now a spray application. Previous to here, we were talking about asphalt concrete, and asphalt concrete, normally, we're dealing with hot mix. A prime coat is placed, spray application, on the granualr material prior to the placement of the asphalt concrete. Its purpose is to provide bond between the two layers which means it penetrates to some degree, provides sufficient asphalt on the surface to bond with the asphalt concrete that we place on top. Another type of coating is a tack coat, and on a conventional overlay system, we apply a tack coat now on old pavements. Usually tack coat is like two tenths of a gall-one tenth actually about one tenth of a gallon of an RS uh emulsion or an RC cutback, something of this order, just to give a tacky appearance to the surface of the old pavement so that when you put new asphalt concrete down, again, you get good bond.

A: . . . per square. . . .

L: Oh, per square yard. Ten--everything--when we talk about spray applications, it's per square yard. The

prime coat's more like point three five gallons per square yard. What other type of spray application do we have? Well, if we had a macadam base or a base that we want to penetrate that's open enough, we can actually spray hot asphalt cement or tar at a suitable rate so that it penetrates into that granular material. And, in fact, many shoulders, even today, are constructed using a penetration macadam type construction. Now we come, then, to the surface where we have spray applications. In the surface, we have seal coats and surface treatments. Surface treatments are usually single, double, or triple. And what you do there on a surface treatment, you basically start out with some forced stone. Well, first of all you spray it with asphalt. Spray the--the surface of the old pavement or the surface of the limerock base or base forced material with asphalt, and you put on a layer of fairly uniform stone which may be fairly large, roll it, and then you have, if you have enough asphalt, you'll have the aggregate push into the asphalt and firmly embed it. Now the depth of embedment should be somewhere in the vicinity of about seventy percent or so. If you have too much asphalt, it'll come to the surface, and you'll have a problem. Well, now, initially, if this is going to be more than single uh surface treatment, a little extra may not hurt. But you got to be very careful by the time that you get to

the top that you don't over do it. And, in fact, if you get too much down here and it sets up and hardens, that means that your other aggregate will not key into place as well, and you're going to end up with a flushing uh seal coat or uh surface treatment. Well, after the first layer, if you wanted to, you could then put in a little smaller stone, and by the time you're through, you have this choked up where you have a very fine surface. This'd be single, double, or triple, depending upon your purpose. Clearwater. Anyone that's down in Clearwater, look at their city streets, and you'll see many good, well-constructed surface treatments down there. The fellow that does that, the contractor, knows what he's doing. And he, in fact, varies the amount of asphalt depending upon the location of the pavement. He comes up on the curb line; he shoots a little heavy to provide a really good seal along the concrete curbs. And he does various things in this fashion in order to get the best job.

A: . . . rural areas. . . .

L: And it's an excellent way to improve skid resistance if you wanted to do that and assuming you put in the proper type of aggregate.

A: . . . sophisticated. . . .

L: As long as people know what they're doing, that's true. It's cheaper in the long run.

A: . . . cheapest. . . .

L: New pavements where you go right on top of the base forced, or for old pavements if you want to protect them from cracking, you catch 'em before the crack. Uh that'll extend the life tremendously. And remember, you've got a lot of asphalt there so that you have much more ability to withstand the formation of cracks through that material. Seal coats. That can be one of two things. Just asphalt in the form of some type of very thin fog spray to permeate and seal off the surface, to extend the life of the pavement. We have uh products such as Reclamite. You might have heard of Reclamite, and it's supposed to rejuvenate the pavement somewhat and seal it off. So you spray that on the pavement, and supposedly it's going to impart these uh beneficial properties. However, you don't want to do that if you have a pavement that's already had a crack, a lot of excess uh asphalt being extruded. So in that case, that type of approach would not be adequate, but you might want to go to a sand and seal where you apply that thin coat and put sand over it to take up the excess material. They do that here in Gainesville periodically, and sometimes it works pretty nicely, and, then again, they may end up with a mess. They've actually made it worse from the standpoint of skid resistance. Uh personally, I think that these are uh noncost-effective measures except, perhaps on very localized, low traffic volume streets. Arterials, at

least go with surface treatment or look at some other alternant. This leaves us, I think, with uh one major uh type of construction that's left, and that is a slurry seal, and the slurry seal is constructed using material that normally passes number eight sieve. It has an emulsion which now they're trying to use what we call quick-set emulsions. It's mixed up in--the two are blended together and mixed in a mixer similar to a motar mixer or a concrete mixer, put into a screed box and is screeded out to a thickness of quarter of an inch or somewhat, three sixteenths or maybe over a quarter of an inch. The basic purpose is to provide protection to the underlying pavement, improve skid resistance, extend the life of the pavement, and maintain your elevation controls like on city streets. You probably have no business ever using slurry seal on any major arterial unless you have some type of elevational control such as curb lines or something of this sort. If you do have a thick pavement, though, keeping this in mind, the only other way to maintain curb lines is go back to recycling. You can recycle and maintain that elevation. Now, there's numerous construction procedures, and we'll talk about some of the construction procedures later as we go along. I'd like to start out, and I see we're running late. I don't know if we have another class coming in here or not. Uh let's look through uh just a couple of slides.

I want to just give you indication of what we'll be talking about next time, in more detail. Let's start out with plants, and the plants we're going to deal with are primarily of two or three types. One is batch plant where we aportion materials, put them into the mixer in a batch form, and dump them, and recharge the mixture--the mixer, or a continuous plant where the material feeds in in a continuous fashion. It is mixed. It's conveyed into a storage hopper for dumping. The other alternative, of course, is to go into a different form of mixing which, in fact, is continuous, and that's the drum mixer. The drum mixer is, in fact, a continuous plant, but a different format. As we look at this, the flow of material, we start out with our aggregate storage in one fashion or another. It goes through drying. This applies both to the standard batch and continuous plant, usually a sieving procedure to separate the hot material into bins of different sizes. And then from these bins, you're proportioning material along with proportioning the asphalt and putting that into the pug mill for mixing and eventual dumping into the truck for delivery to the job assignment.

A: . . . how many. . . .

L: You don't have to have four sieves. Sometimes you might have a two-bin separation.

A: . . . that. . . .

L: You'd just have a--no, you'd have a course and a fine. The filler would go into the fine bin. Uh if you have mineral filler, that would be always considered as an extra supply, and usually the mineral filler feed is a cold feed. Mineral filler is not hot, unless, unless, you're recycling material from your cyclone dust collectors or bag house directly back into the mineral filler feed, then it could be hot. If you're putting in a natural filler such as an Iowa Loess, using high grade lime, or rock dust that may be available, most of that is going to go in cold. It's not going to be heated. It's going to be dry, basically dry powdered form. This just illustrates some of the loading devices, clam shells, and so on that are going through the cold bins. When we charge the cold bins, the cold bins are controlling the proportioning of the material. If you don't have those gates set properly on the bins, or if you have the wrong materials going into the cold bins, it's impossible for you to meet your job mix formula or plant mix formula. In other words, you have to have that correct. The hot bins are only a--a secondary measuring device. And waht would happen here is that you could adjust your hot bins to give you the right mix, but you'd end up with one hot bin that's going to always be running out, and another one that's always filling up, and you're going to be dumping material on the ground. You're not going to be

utilizing it all. So that the proportioning or maintaining of your aggregate gradation--it is essential to start right back there at the cold bins, and as that goes into your drier, into your plant, and proceeds on. And the rest of these slides--I'll tell you what, we're going to cut it off at this time, I think. Or do we have another class out there?

A: . . . usually. . . .

L: Let me just check and see. Yeah, there's some people there. So, let's just cut it off at this point, and we'll pick it up here on Wednesday and discuss different elements in the plant. We'll discuss what control measures need to be taken, and then we'll proceed into a little bit of discussion on drum mixer plants and then field operations. So read up on plants. Make sure you've gone through the plant manual. The main--the most important thing there is to scan through there just to pick up the main--the major uh most important aspects of plant operation. Yes, plant manual. So that's it for today.

APPENDIX E
MEDICINE 1

(L: Lecturer; A: Audience)

L: I obviously can't top either--either one of those announcements. The--the free--free beer or the party, whatever, is tonight, but uh--

A: . . . party. . . .

L: So at any rate, what we're uh--

A: . . . let's go. . . .

L: That one's too tight.

A: . . . .

L: Uh since the uh schedule that I've uh kind of figured out uh is different than is in your syllabus, I thought I'd go ahead and--and list it there. Uh today what we're going to do is talk uh mostly about uh uh--well, first of all, about superficial structures in the--in the lower extremity and--and then some about the muscles, but uh we'll get a little bit ahead of ourselves today. And then on Thursday, we'll do uh the hip joint and lumboseral plexus and the gluteal region and hamstrings which will be about a day ahead. And then on the next Monday, we'll--we'll uh do the thigh muscles and papliteal fossa and the knee joint. So if you want to read ahead or--or uh--

A: . . . .

L: And then you can uh we'll uh go from there, but the last day will be mostly this functional anatomy of the spine and the lower extremity. But the main thing, now, we'll cover the hip joint and the knee joint a little bit ahead of uh the last lecture here. Okay, that's pretty--was straight, wasn't it? Uh so what I want to start off with mainly with uh uh some of the vasculature of the lower extremity, particularly the uh the uh venus uh drain. One thing we should uh we should uh keep in mind as far as terminology is the whole thing is the lower extremity, and--and uh the part that the femur is in is the thigh, and this is the uh the leg down here. So, even Dr. Snell every now and then talks about the leg when he really means the lower extremity, but we'll--we'll let it go--

A: . . . .

L: in his case. Uh the thing to--and we'll--we'll dwell on this a little bit more later, uh the thing to keep in mind about the--the lower extremity is that--that it's uh really internally rotated uh in about a hundred and eighty degrees in comparison to the upper extremity. That is uh get a piece of chalk--do it this way. In the uh embryo, I know you uh finished that--that course already.

A: . . . forgotten. . . .

L: That if--if this is, you know, this is the early--early embryo, and uh--

A: . . . .

L: And this'd be uh, you know, the upper limb bud. Uh this'd be the lower limb bud. As the limb--limb bud grows out, it grows out with the uh with the uh thumb--thumb up in this fashion, and the lower limb bud grows out essentially in the same direction with--with the big toe being the superior aspect. So it's the--if you get the upper extremity back in the embryonic position, it would grow out pretty much like this, that is with the thumb up. And that is why uh the cephalic vein is called uh that because it's on the some--thumb side, and the basilic vein is on the--on the base of the uh of the limb bud. Uh the same is--is true of the lower extremity, uh but the complication is that--that the lower extremity has undergone about a hundred and eighty degrees of--of internal rotation in comparison to the upper extremity. That is, if--if you want to get the lower back into the--to the embryonic position, you would have to externally rotate it so that--so that the big toe is up like the uh thumb is. And so--and many of the structures, not only the plexuses, that is the nerve plexuses, the veins, and ligaments, uh but many of the small muscles around the hip uh reflect this--this internal rotation, and we'll come back to that off and on. Uh but you can assume

the uh same position yourself if you, you know, if you internally rotate the upper extremity so that your elbow sticks out like this, and that would be where your kneecap is, or the patella. And then the dorsum of your hand is--

A: . . . .

L: would be the dorsum of your foot.

A: . . . .

L: You don't believe that, do you?

A: . . . .

L: And uh the bottom line is that uh that the lower extremity has uh undergone about a hundred and eighty degrees uh of internal rotation in comparison to the upper extremity. So most of the things that we'll talk about are--are twisted uh to a certain degree, but--and that's somewhat true of the uh of the veins as well. So what we want to do with this is put on the veins of the uh superficial veins of the lower extremities, and talk a little bit about uh varicosities and that sort of stuff.

A: . . . .

L: Did we lose somebody already back there?

A: . . . sixty pencils. . . .

L: Auctioning them off? Well, the uh the thigh and the--the leg are completely encl-enclosed in deep fascia, and it's very thick, extremely thick, and in certain areas, it's even a thick and independent-like structure.

But--but the fascia of the thigh, uh it's called the fascia lata, and it's essen-essentially just like a--a sleeve or a pants leg that hangs down and is anchored to the--to the inguinal ligament that would be running across like this. Uh the membranous layer of the superficial fascia is--is tied down to this fascia lata and forms a seal between the superficial fascia of the abdomen uh and the thigh. And you remember when we talked about the extravasation of urine due to an injury of--of the urethra, and how the scrotum and part of the perineum will swell, and then the swelling will go up onto the abdominal wall. Well, it won't go down into the thigh because the membranous fascia is packed down to his--this dense fascia uh the fascia lata. So you'll see the swelling or discoloration up on the abdominal wall, but--but you won't see it on the thigh, you won't. Uh about a finger breadth or so uh below the inguinal ligament, there's an opening in the fascia lata, and this is just called the saphenous opening. And, as you might guess, the--the saphenous vein goes through that. Uh the saphenous vein begins down on the dorsum of the foot and essentially would be the counterpart of the--of the cephalic vein in the upper extremity. And it passes anterior to the little ankle bone that sticks out there, and that's called the medial malleolus, or the little hammer. And uh it passes superiorly and goes just behind the knee joint,

and then comes on up on the thigh and--and goes into the saphenous opening. Of course, there it's going to terminate uh the femoral vein. But what--and what we're looking at is--we've removed the skin, and uh look--we're looking down on--on the--the deep fascia. We haven't haven't gone into the deep fascia. So this is the saphenous vein.

A: . . . on top. . . .

L: Excuse me?

A: . . . external. . . .

L: It's external to the fascia lata. And since--since this is the large one, this is the great saphenous, and uh it--it just drains uh in on the superficial fascia from--from this area of the--the lower extremity. Of course, there are lots of little tributaries that uh run off of it. In some cases, there's uh there's an accessory saphenous that runs down like that, uh but that won't be present in--in all of the cadavers. The uh lesser saphenous, which is the counterpart of--of the basilic in--in the lower extremity, uh arises on the lateral side of the foot and passes behind the lateral malleolus, and the less--the uh small saphenous passes up behind that and goes through the deep fascia uh behind the knee. And uh that uh space behind the knee is called the--is called the popliteal fossa. Where this is the cubital fossa. This is the popliteal fossa back there. So it goes through the deep fascia,

and that's where it joins the--the deep vein. Uh if we were to uh draw this lateral view coming around here, then the great saphenous would--would come around uh like that, and frequently there's a--a communicating vein between the two. This is the small saphenous, and uh then this is the great saphenous here, and uh this is just called the communicating branch. And so the--the lesser or small saphenous drains pretty much the posterior aspect of the uh and the lateral aspect of the leg. Uh whereas uh the great saphenous drains the medial aspect of the leg and almost all of the thigh. There are some--well, the uh the art--since the femoral vein lies right under the saphenous opening, uh the femoral artery is right there as well. And we can draw in some of the veins and--and accompanying arteries that we'll--we'll look for in the lab. They appear, and some of them we've--we've seen parts of previously. Uh the veins that empty into the saphenous right as it goes into the femoral uh there's one, and I'll put these--I guess we may as well label them as we go along. Uh this is the uh superficial uh external pudental.

A: . . . from the saphenous?

L: Yeah, it drains into the saphenous uh huh. It drains into the saphenous.

A: . . . kind of hard to see. . . .

L: Okay. You mean the vein or the uh the writing?

A: . . . .

L: Uh should I go with uh maybe a different color? Let's--let's put--I'll put it in red, but I'll write down arteries and veins. So uh you have to, of course, understand that the artery comes off the femoral artery, not off the saphenous vein.

A: . . . .

L: That's elem-elementary after, what, eleven weeks of anatomy you got? Anyway, this is the superficial external pudental, artery and vein. And then also in this area, there's going to be uh the uh superficial epigastric coming up, artery and vein again, and then coming out of this hole, uh the artery. That would be the uh superficial uh iliac circumflex vein, and we have the uh deep iliac circumflex, and the uh deep circumflex will--branches off the external iliac artery. It seems as if uh branches that are going to supply the--the superficial fascia, that is the outer part of the abdominal wall, uh come out below the uh inguinal ligament so that then they can come out--up anteriorly--uh superiorly and supply the--this area. Those that are going to supply the deep part of the abdominal wall come off the iliac uh before the artery goes into the inguinal ligament. That is before it changes from external iliac to femoral, right before it goes over there. So uh the superficial vessels uh come out and then go up on either side of the uh of the inguinal

ligament, but these are structures that we'll look for, and these are in superficial fascia. Of course, there would be uh veins that would run along with them as well. So that's pretty much that area. Uh the uh external iliac circumflex, and the superficial epigastric, of course, supply the abdominal wall, primarily, and the upper part of the thigh. Uh the superficial external pudental uh supply the mons and the scrotum and so forth in that area. Well, one of the--the saphenous--the term saphenous means 'obvious' and, of course, it would prob-probably relates back to the fact that--that uh those people that had varicous veins or enlarged saphenous veins, they were obvious. Uh and it relates basically to the anatomy of the system. That is why you get varicous veins, or why anyone gets varicous veins. Uh maybe to illustrate that, we can just uh draw kind of a--a basic diagram and show where the uh valves are. There are essentially--essentially three types of veins in the--excuse me? Did I do something? Somebody's throwing grapes back there. People are going to get the--the right--wrong idea.

A: . . . .

L: There are three types of uh of veins in the lower. There are the superficial type that we've already talked about, uh and then there are connecting veins uh that connect the superficial veins with the third

group, or the deeper veins. And then the third group is the deep. And so uh this channel out here would--would represent number one, that is the superficial uh veins. And then number two would be the connecting--these would be the connectings. And then these would be the deep uh type of vein, in there. Of course, between these two uh groups of veins or types of veins, that is between the superficial and the deep, uh would be this layer of fascia lata or--or deep investing fascia, or as I say the fascia lata. And then, of course, if we wanted to, we could put--uh the skin would be sitting out here someplace. And then this would be filled with--with loose connective tissue or fat and that sort of stuff. Well, the uh the valves in this system, of course in all of the veins, at least the deep and the superficial, are going to inhibit retrograde flow. So the little leaflets--leaflets of the valve are going to sit like this. And uh so that as the blood goes superiorly, uh and uh once that pressure stops, then the attempt to get--uh go inferior will be blocked by these little valves. So the--so the proper directional flow is dependent on the--on the valves in the veins. And of course, in these connecting veins, uh the direction of flow in the normal--uh is from the superficial uh to the deep vein. So the blood in the superficial vein can either go superiorly, or it can go uh into the deep vein.

And as we said before, the valves in all cases are going to inhibit retrograde--retrograde flow. So these valves would, of course, would inhibit the flow in that--in the inferior direction and would support it going that way. Now the flow uh is propelled--or the momentum for it comes from muscles that--that will be sitting next to the veins. That is, every time a muscle contracts, it's going to squeeze the--squeeze the vein and force blood uh only in one direction if--if the valves are--are uh functioning. And whenever the vein is squeezed, it will force blood uh superior. Also, there may be arteries that lie next to the--to the veins, and every time the artery pulses, it will push on the vein and--and uh squeeze it. And uh since these valves are blocked, uh it will force blood up that way, and then it can't get back down. Well, what happens, uh apparently, depends on a number of things. Uh one, uh there seems to be a tendency--a hereditary uh tendency uh for the elasticity in these connecting veins to be lost in some individuals, and if that--if the elasticity is lost, then--then these become dilated. Other reasons may be that--that there may be a tumor somewhere upstream, so to speak, so that uh the blood is working against the gradient. Uh frequently in pregnancy uh varicosities develop because of the increased--increased abdominal pressure or pressure on the iliac uh by the fetus and the pelvis. So either

due to the increased pressure or some hereditary uh defect, what happens is that--that these uh connecting channels uh become dilated, and then--and so that the valves uh don't quite reach. That is when they--when they close, it--it won't form a good seal. And then a secondary--secondary effect then uh is that the superficial veins uh become dilated, and their valves uh don't seal either. So what happens is that every time uh these muscles contract or whatever tends to force blood uh this way as well as this way. And because of the fascia lata and the heavy musculature and the dense connecting tissue, there really isn't much area for these deep veins to expand. So what happens is uh that the superficial veins uh expand, and uh blood stasis occurs. And you end up with varicose veins. Uh the cure, of course, one of the early--early treatments--it isn't a cure--but one of the early treatments is to wear elastic stockings or something like that, where you can uh, by a mechanical process, you can put pressure on the skin and the superficial veins against this deep fascia. And so that essentially inhibits--inhibits this flow and probably equalizes the pressure between this venous system and the deep venous system. A secondary, uh more severe I'm sure, is uh where they go in and uh tie off these uh connectors. Uh surgically open up the--the--the leg. Generally it occurs--varicosities occur in the leg and not much

above the knee. But they may go in and--and tie off the connecting veins, and that inhibits the backflow. So the pressure, then, at least the blood that's in--in the superficial veins, that pressure isn't any greater than it would be from its own flow. That is, it eliminates this--this high pressure flow. Another system is--uh another approach is to uh do what's called vein stripping. And in that case they run--they run a little, as I understand it, a little fish hook thing down through the great saphenous vein and make a little uh incision down here someplace, and uh put a little hook on the end of it, and then just strip it uh back out. Also, they run it in up at this end and pull it on that end. And then pull it out and tear it all out. Yes?

A: . . . what would happen. . . .

L: Well, they just pretty much close off.

A: . . . .

L: Well, sure, there would be lots of clots every place you tear--

A: . . . .

L: tear out. Every place you tear one of these, it would clot over and scar down, and--and new uh channels would probably form, not necessarily actual veins, but--but existing venous channels would open up and that sort of thing. And there--yes?

A: . . . saphenous vein. . . .

L: Right. Yes. For vein stripping, they generally just strip the sapenous vein. Uh they--along with it, they'll--they'll tie off the perforating, in most cases. Yes?

A: . . . the problem. . . .

L: Well, number one, uh it's extremely painful uh because of the tension. When you--when you uh stretch these veins, it hurts. Uh number two, you'll run the risk of--of getting clots because of blood stasis. And, once you get a clot that uh that doesn't stay where it's supposed to, that in itself is painful. But, of course, you run a great risk of an embolism that's going to end up in the lungs and that sort of thing. Uh maybe uh Dr. Lawless could tell us more about the vein stripping business, uh could you? I uh--

A: . . . adequate circulation. . . .

L: Also uh one other more recent use of the saphenous vein, of course, is for uh uh bypass operations in uh in cardiac surgery. That is, that's the vein that--that they take out, and uh the primary thing, of course, is to put it in in the right direction. In other words, if you--

A: . . . .

L: If you put it in with the valves backwards, it isn't going to--it isn't going to work very well.

A: . . . deep vein. . . .

L: I'm sure there are--there are variations, but uh this seems to be the most common uh common uh ideology of uh

varicosities. So what--but the main problem is that once that--once these valves give way, then you have high pressure. Yeah?

A: . . . was wondering. . . .

L: I don't know. Dr. Lawless, is there another way of preventing the--the varicosities or problems associated with pregnancy, other than the elastic stockings and that sort of thing?

A: . . . maintain good tissue condition. . . .

L: The--uh uh it's kind of like people that have uh have had mathical--mathical rastectomies.

A: . . . .

L: You can also do aortic arches. Yave you ever tried those? Aartic-aartic orches? No? And a lot of other stuff. It's--I think it's kind of like after radical mastectomies where the tissue, once it gets stretched uh out of shape, and uh elastic tissue loses its elasticity, uh then you either have to compress it mechanically or--or alter the pathways or something like that. Once it gets stretched out, it isn't going to recover on its own. Well. Okay. Any more questions about this business?

A: . . . how often. . . .

L: How often?

A: Yeah.

L: Uh I don't know what the frequency is. Uh the uh--

A: . . . .

L: When you do the lab today, we can count them.

A: . . . had to ask. . . .

L: That's a good idea.

A: . . . .

L: I don't know which you are, but whoever asked the question automatically volunteers. The uh--there's a fair amount of uh statistics about where the valves sit in relation to the ostium, that is the opening out of the saphenous vein, and where it goes into the femoral vein, and studies have been done there. Whether--there is--how many--what percent of the people have veins in the external iliac and which ones are the femoral and all that, but they're--they're uh reasonably frequent. Uh you can check these on--on your arm, you know. Uh by shutting off--either uh by squeezing in the axilla, you can see where little valves on the arm are.

A: . . . large veins. . . .

L: Uh yes, primarily. Okay. Well, let's uh go--go on to the next uh--one thing that uh we've uh--we need--we need to mention here before we go on, and something we've--we've talked about before--remember when we did abdomen and pelvis and perineum, we talked about uh superficial inguinal nodes, and uh--ah hah!

A: . . . .

L: At any rate, anyway, these nodes uh--there are, oh, ten to fifteen of them generally. And they form uh pretty much uh, not really, but a structure like a T. That is,

one group runs parallel to the inguinal ligament, and the other group runs parallel to the uh saphenous vein. And uh, of course, uh the superficial inguinal nodes are going to--are going to drain the uh external genitalia of both male and female, uh the lower half of the anal canal, uh all of the lower extremity, uh the buttocks, uh pretty much the trunk below the uh umbilicus. And ah from there uh the venous channels will go through the saphenous opening, uh and then they'll go into the femoral nodes. And then the veins--the lymph will pass under the inguinal ligament into the external iliac node into the common node in the aortic and so forth up into the cysterna chyli. But--but this is where the inguinal--the superficial inguinal node and the popliteal node lie. Generally, there is one or two in the popliteal space, but uh not very often do you find them there. Remember, those channels would run--would run with the deep veins. Let's look at this one next. What this is--uh hopefully represents in a picture of the anterior part of the thigh. This would be the patella, or the kneecap here, anterior superior iliac spine, pubic tubercle. And what essentially--what we've done is uh to cut through the fascia lata here and the fascia lata here so we can look in on the--on the front part of the thigh. What I want to put on this is uh some of the muscles and also the make-up of the femoral

triangle. Uh if we put the inguinal ligament back again, here, and kind of put the boundary between the abdomen and the--and the lower expremity. One of the muscles that we won't really talk about in any other--in any other diagram uh is this down here. It comes from the outer part of the iliac crest, right behind the anterior superior iliac--iliac spine. And, it's really enveloped in a--in a--a fold of the fascia lata. And its fibers actually insert into the deep fascia of the thigh, and this muscle is just called a tensor uh--

A: . . . .

L: What? Did I do something? Say something? Drop something? What?

A: . . . .

L: Uh at any rate, this is just called the tensor uh fascia lata, and it arises from the ilium. You go into the ilium and search into this--into this tract or into the fascia lata. And the fascia in this area on the lateral part of the thigh is very thick and heavy, and is actually made into a tendon. And the tendon is called iliotibial track. And this uh because the fascia passes down below the knee and inserts into the fibula and into the tibia. Uh the tensor fascia then, actually, have some function uh across the knee joint. In that case, it helps to extend the knee somewhat. Uh it is also--

A: . . . .

L: Excuse me?

A: . . . where. . . .

L: Uh it inserts pretty much around the area of the--of the knee joint into the head of the fibula uh and onto the tibia on--along here, but it--but the tract passes posterior to the axis of the knee joint. So--so it's a knee extensor somewhat. And its uh main--well one of its functions has to do with--you stand erect uh with the knee fully extended. Then this will help you maintain the--the knee in extension so that you use the minimum amount of--of muscle activity. Uh it's also a hip flexor--a very weak hip flexor and uh medial rotator. Uh I don't know if you've uh watched gymnists when they do--it's especially hard to do straight leg raising because when you do that, your hamstrings and other things bind on it, but--but these uh people have extremely large uh tensor fascia latae. And you can really see them standing out, particularly when they do straight raising. You know, when they lift the leg up straight, there's a great big buldge.

A: . . . .

L: That--that--that's your enrichment for the day.

A: . . . .

L: Of course, we don't--

A: . . . .

L: Those of us who go to the gymnastic things are interested strictly in the kinesiology of muscles.

At any rate, so much for tensor fascia lata. Uh there's another muscle, though, that comes from the--the anterior superior iliac spine and winds across the--the thigh and ends up going down and inserts into the medial--medial aspect of the tibia, approximately. And this muscle's called the sartorius. And uh sartorius uh means 'tailor'. And what--what this muscle does is uh is--because it comes from the anterior superior iliac spine and goes to the tibia, it crosses not only the hip joint, uh but also the knee joint. So it's going to function across both joints. And what it does is, it has the function of--of what you do when you sit down and cross your--cross one leg over the other. That is, it--it flexes the hip, and it externally or laterally rotates the thigh, and it flexes the knee. And this is uh the position that the uh tailors used before sewing machines when they sat down and sewed, essentially, on the knee. So, that's why it's called the sartorius. At least that's--that's my rationalization of it. So anyway, it's the longest uh longest muscle uh in the body. That's another bit of enrichment. Well, what this--what the sartorius does is pretty much divide the thigh into two--two general regions. There's a lateral region, and out in this area uh is where the quadriceps are. And there--I won't put the quadriceps on here, uh but we'll uh just--just mention them. Uh what, of course, <u>quadri</u>

means 'four', <u>ceps</u> 'head'. So it's a muscle that has four parts to it. First part's the rectus femoris, and uh since this one crosses the hip joint, that is, from the anterior inferior iliac spine uh to the tibia, it also will have some effect on hip flexion as well as knee extension. So, of all the four quadriceps, only the rectus femoris has anything to do with the hip joint. All the other three that I'm going to list now uh function only to extend the knee. So uh in that sense, it's very much like the triceps. Okay. So we have the rectus femoris. Then the other are--are vastus lateralis, and then the next one is vastus medialus. And then uh the fourth one of this group is the vastus intermedius. And uh, as I said, keep uh in mind that--that only the rectus femoris has anything to do with hip flexion because it crosses that joint. Uh these other three uh arise on the femur and insert into the tibia through the--through the patella. And in that sense, they would be like the medial lateral head of the triceps, where the rectus would be like the long head of the triceps. So uh this--this area lateral to the sartorius uh is pretty much femoral nerve territory. These are all innervated by the femoral nerve. And once we get medial to the uh to the uh sartorius, then that's pretty much uh obturator nerve territory for uh the muscles of the uh adductor. And one of these arises from down here--arises from the

uh body of the pubis and then passes laterally and kind of disappears behind the sartorius and goes down and passes to the femur. And this is going to be--this muscle is going to be called adductor longus.

A: . . . adductor. . . .

L: Adductor longus. So with the adductor longus uh and the uh sartorius and the--the uh inguinal ligament, then we have a triangle, and that triangle is called the femoral triangle. So uh within the femoral triangle, then, we can--we can point out structures and uh--

A: . . . .

L: Yes?

A: . . . book they keep. . . .

L: Right, the lateral edge of the triangle. Uh that's essentially what I've--uh it's--you can think of it pretty much where ever you want it to. I mean, it's easier just to think about it as the muscle itself and not worry much about--but uh if you think about the medial edge as the border of the triangle, then adductor has to be part of the floor of the triangle. For our purposes, it isn't going to make that much difference.

A: . . . .

L: Uh that's--that's uh instructor hedge number twenty-three.

A: . . . .

L: Uh if we--if we put the uh the femoral artery in, it's going to lie uh just about equidistant between the anterior superior iliac spine and the pubic tubercle. So we can go ahead and just sketch in the femoral artery. We've done this, a little bit of this, before. Filled some of this figure before. And then medial to that is going to be the femoral vein. And then uh medial to that is going to be the lacunar ligament where it winds back and folds back on itself. And then it comes off the inguinal ligament, folds back, and runs up along the pectineus line. So that the most medial part of--of this space uh will be the lacunar ligament. Okay. Let me erase some of it. Uh the floor of the--of the triangle uh is uh made up of uh of iliacus, mainly, and uh psoas. And remember how they come down over the front part of the joint. So--plus there's another little muscle uh that sits right in this area called the pectineus, and you remember the pectinate line where the uh the lacunar ligament runs on up on the pectinate line. Well that uh reflects the area where the pectineus passes into the superior rings into the pubis. So, if we were to look behind these two, we would see iliopsoas here and pectineus here. I didn't put them in because it gets uh pretty messy if we do that. But the point uh to be made uh from that is that since the basilic sits over here uh the femoral nerve uh is associated with the uh iliacus

themselves, and it's actually in a little separate sheath, but it runs in the fascia of the iliacus. And so, then, if we--if we go back to the uh to the--to the mnemonic that we had some time ago, of course, the N, A, V uh there's an empty space here. So the mnemonic then is the N, A, V, E, L, a navel. That is nerve--if we're going from lateral to medial, the nerves, the arteries, the veins, the empty space, and then the lacunar ligament. So uh in many cases, you're asked to do uh--or you will be asked to do uh venal taps or arterial taps. And if you keep this--this relationship in mind, uh and you remember that the uh artery is going to be about midway between the anterior superior iliac spine and the pubic tubercle, uh then you can find uh the femoral artery palpation, and you know that the vein is going to be just adjacent to it medially. And the nerve is going to be lateral to it. Yeah, question?

A: . . . that whole. . . .

L: Right. We'll--we'll get to the empty space. The empty space is next. I'm glad you mentioned that. Uh the uh empty space essentially is filled with lymphatics. There may be one or two nodes, and that's how the lymphatics, that you know, that go through the saphenous ring and become associated with the artery and vein, how they pass up into--into the abdomen. Now uh during development uh and growth, the fascia of

the abdomen, that is the--the uh transversal--the transversalis fascia gets stretched down over the uh anterior aspect of these vessels, and then the fascia of obturator, not obturator, but the fascia primarily of--of the cellus muscle makes up the back part of the--this area. And wrapped around these structures is this fascial compartment--uh comes down, and it comes down and narrows around each one. And then it comes back up and is attached--uh can you see that? That--what--what I'm drawing in is a--is a layer of fascia that comes down, stretched down from the abdomen. In this case, it's transversalis fascia anteriorly and cellus fascia posteriorly, and it seals--it forms a tight teal--wraps around each of the vessels right here. Well uh the space between uh the fascia of the femoral vein and uh this lateral edge stuck to the lacunar ligament, uh that area uh right in here then, see here, uh is called the femoral canal. And if you follow--if you run inside of the abdominal cavity, and you look down below the inguinal ligament right next to the inguinal ring, then uh you'll see a little uh depression there. And if you could look into that area, that is the space between, actually, the inguinal ligament and the vein, you'll see a ring there, and that's just called the femoral ring.

A: . . . there's nothing. . . .

L: Lymph nodes. Lymph uh--in the ring--uh the ring is just the upper end of the femoral canal. It is the uh

superior end of the femoral canal. Uh and the femoral canal contains, then--or the femoral--the femoral sheath contains the femoral artery, the femoral vein, and the lymphatics of that area, the deep lymphatics. Uh the femoral nerve is not in the femoral sheath. And the femoral canal is a part--or is internal uh to the femoral sheath. Of course, the femoral canal is the area where--where uh femoral hernias occur. Inguinal hernias--inguinal hernias, of course, come out through the--the external ring, and that's superior to the pubic tubercle. Whereas femoral hernias come out, and the mass that you palpate there would be lateral and inferior to the--to the pubic tubercle. Uh a differential diagnosis, of course, would be superficial or deep nodes in that area. Yeah?

A: . . . the empty space. . . .

L: Yeah. Okay. Let me--I'll--let me uh outline where the empty space would be. See the empty space would essen--that would be the femoral canal in the middle. It's much larger, and it would be--but it's--just think about the femoral sheath as a sleeve, you know, that gets pulled down on the vessels as differential growth occurs. And because uh it's attached over here to the inguinal ligament, it forms a cavity or--or uh a vacant area, except for whatever lymph nodes are in there. And uh--so once that uh that space is there, it's a potential defect in the abdominal wall. And you

can uh herniate this or--or the subserous fat or whatever. And, generally, what happens is, depending on how severe it is, that is if a piece of the bowel gets pushed down in there because the ring is very small, uh it's--it's pretty serious. Uh hernias frequently have large areas that aren't uh tightly uh tightly bound, but this is a pretty tight area, and so these can be more dangerous, really, than inguinal. That is, as far as uh uh necrosis of the bowel and uh cutting off supply of blood and that sort of thing. Okay? So what we wanted to do here mainly was deal with the boundaries of the--of the femoral triangel, uh go through femoral sheath, that sort of thing. Okay.

A: . . . what's. . . .

L: What's it do? Well, really, it doesn't--doesn't do anything that I know. It's just a reflection of--of the inguinal ligament back along to pectinate line. It's where-remember the--I guess you could say that it helps to anchor the--the medial end of the inguinal ligament. But--as the inguinal ligament comes down like this, it attaches to the pubic--pubic tubercle, and then it goes back on itself to run along the pectinate line. And that little depression on the lacunar is just called the lacunar ligament. I don't know that it has any uh any uh recognized function. Okay, well then, why don't we go on. Any more

questions on this? We'll essentially do this in lab--in lab on Thursday. Uh I should say before--before we go on, that the femoral triangle is--is kind of like a function--function--a funnel. That is, if--if this is the femoral triangle coming down like this, then uh the tube of the funnel uh is the uh the femoral--the femoral canal or adductor canal or. . . . So, if you take a cross section right through here and look at it, uh this is the femoral triangle. This is the adductor canal, and we're going to cut a section across this. Uh the roof of it would be sartorius. This is adductor canal, and the roof would be sartorius, sitting right like this. And coming in from the side is the adductor magnus.

A: . . . .

L: How about longus? Adductor longus--adductor longus.

A: Okay, we'll get it--we'll get the magnus in just a minute. Now, so anyway, so this is adductor longus. So the floor of it is adductor longus, and then the medial wall uh would be one of the vastus muscles, the vastus medialis, and that comes around like this.

A: . . . .

L: So that if we--if we were to draw vastus medialis on here, it would be coming around like this. The rectus femoris comes down, and then vastus medialus comes in a makes up the--the large mass--

A: . . . .

L: Yeah, this is--this is as if we cut across here and then turned that part up and looked in--in at it. This is essentially a cross section uh through these muscles right here.

A: . . . .

L: So what we're looking at is--is a cross section of the adductor canal. It's also called uh the subsartorial canal. It's also called Hunter's canal, after a surgeon, an anatomist-surgeon in England.

A: . . . point out. . . .

L: This?

A: . . . .

L: This?

A: . . . .

L: This blackboard?

A: . . . .

L: Yeah. That was somewhat--femoral canal--shouldn't've slipped that in on you there. Femoral--femoral triangle. This is the femoral triangle. And uh in--just uh--this would uh--this diagram would just represent the femoral triangle here. And the point I was trying to make is uh that the femoral triangle is kind of like a funnel in that it leads in into the adductor canal.

A: Oh. Okay.

L: And so that--this would be--this would be the adductor canal here.

A: . . . fascia. . . .

L: Well.

A: . . . .

L: This? That? It's just a diagram. It's just to represent the inguinal ligament. This--this essentially is the femoral triangle, if you want to think about it.

A: . . . roof. . . .

L: The roof? Uh the roof of the adductor canal is the sartorius, the anterior part of it. I knew I shouldn't have tried this today. I only have about another hour of stuff. No.

A: . . . .

L: No, no, just one diagram. Yes?

A: . . . femoral artery. . . .

L: Good point. That's why I got my red chalk. So we can go ahead and put the uh femoral artery, uh the femoral vein, and there also are parts uh of uh nerves that pass in there. So we're really going to list--list the contents of the adductor canal. Uh the femoral artery and vein, uh and uh there are a couple of nerves. One is the--since the medial wall is the vastus medialis, there is a nerve in there that supplies that muscle. And so that's the nerve uh to the vastus medialis. And then this is a branch to the femoral. And, then, also, there's a cutaneous nerve which will branch off to the femoral that runs with the great saphenous vein,

and that's called the saphenous nerve. And uh a nerve that runs in there for a short period of time, but follows the femoral artery and vein into the popliteal fossa and--we'll talk about how that gets there in this diagram--uh a branch of the obturator nerve. So those are the--and there are also some lymphatics that run in there, but these are the primary conten--uh structures that are found in the--in the uh adductor canal. As I say, if you--if you--when you cut the sartorius, and you reflect it, then you'll be looking right into the adductor canal. Okay. We'll see all that tom--in the lab tomorrow. Any problems with this?

A: . . . .

L: Tomorrow? Tomorrow's a holiday. Thursday.

A: . . . .

L: On this? This is--this is the--the anterior, and this is the me-medial, and this is the lateral. Okay?

A: . . . .

L: Well, let's uh--

A: . . . .

L: We got--we still got problems?

A: . . . .

L: Let's go on to this last one then. Everybody get the basketball notice there? I though that was last night.

A: . . . .

L: So this is--is, as you see, uh represents a front view of the--of the hipbone, and the femur and the tibia and

fibula runs into--might--might point out that uh that this is the greater trochanter here. And uh this is the lesser trochanter right there, and that's where the--the iliopsoas passes.

A: . . . .

L: This is an ant-anterior view. Yeah, the lesser trochanter is on the medial side. Um?

A: . . . .

L: Trochanter means 'runner'.

A: . . . .

L: Yeah, trochanter. I would assume that uh that uh the name came from people that were well muscled. Wherever the muscle attaches to the bone uh, the bone is enlarged there. That is, probably people that were runners or good runners. Uh when they did autopsies or whatever, they found that their trochanters were enlarged because muscle--muscle force--but anyway, trochanter means 'runner'.

A: . . . .

L: This is the greater trochanter right there. And this is the lesser trochanter in there so--and just like in the femur, these are epicondyles. And the femur is a little bit different than the humorus in that there's a large bump that isn't shown here. It's called the adductor tubercle. And we can see that on--on this--on the skeleton right there. It's pretty prominent. It's the bump that sticks up there. Well, what we

want to do with this is to put the adductor group of muscles on, and talk a little bit more about how the femoral vessels get into the popliteal fossa. Uh the uh pectineous--if this little line represents uh the pectineal line, then pectineous is going to arise from up in there. We'll just put this where it's at because it is a pretty superficial muscle. . . . I guess. But uh anyway, it doesn't--it's pretty good sized. Then adductor longus arises approximately from that area. We won't put that on either because we've already looked at it over there. Then, arising pretty much from the tissue tuberousity and a little bit of interior rings of the--of the tissue in this area is a very, very large muscle uh called the adductor magnus. And it has two heads. One head that runs almost directly horizontal in this fashion, and this head is uh called the adductor head of adductor magnus. And it's innervated by the obturator nerve. And then the other head runs down and attaches to the adductor tubercle in this fashion, but there's a big uh gap in the muscle. So the more vertical part uh of the adductor magnus is called a hamstring muscle because it is innervated by a nerve that also innervates the hamstring, which is the large muscle in the back of the thigh. So this is the hamstring head of adductor magnus. This is innervated by the tibial nerve, and as I say, that nerve also innervates the hamstrings. So it doesn't

have uh very much of a function like the hamstrings, uh but because of its innervation, the texts include it as a--as a hamstring-like muscle. Uh this is the most posterior of all and the largest of all the adductors. Uh might mention this. I should go ahead and label here. This opening here is just called the adductor hiatus. The--the next--next layer anterior from this, uh the adductor brevis, sits right in here, and this is almost entirely--is anterior, and from our view would overlie uh the adductor head of the adductor magnus. So what we're putting in here now is adductor brevis, but it covers up most all of the horizontal of adductor brevis--or adductor magnus. So this is adductor brevis, and finally uh--

A: . . . arise from. . . .

L: From the lower part of the pub-the body of pubis. There in that general area. I wouldn't--I wouldn't worry about being--being specific.

A: . . . .

L: As uh far as what--I can always look on the skeleton.

A: . . . .

L: Uh no, more from the body than from the--the--as I recall--I have to look--exactly. Yeah, the brevis comes from the body then. I wouldn't worry about this. The thing to remember, of course, is that it just crosses one joint, the hip joint. Uh then the last muscle that I want to put on this one uh arises from

all this--the entire outer surface of the obturator membrane--and then passes directly lateral to insert posteriorly into the area of the greater trochanter of the hip, and this is just obturator externus. So uh that's obturator externus there. Now, there. A couple of things that we want to do now that we have that stuff on there. Remember the obturator nerve comes out through the obturator--obturator foramen, and there's a little space in the uh superior anterior aspect of the foramen, and this is coated by muscles, and the obturator nerve comes out through that. And as it does, it splits immediately into an anterior and a posterior branch on either side of adapter brevis. So generally the--the posterior branch--let's see here--and, as I say, they split on--on either side of the adapter brevis, and that's the most positive way of--of identifying adapter brevis is when you begin the dissection, and you get things cleaned out. Uh it's kind of hard to--to pick out the muscles. If you start anterior and go posterior, then the first thing you're going to come into is adaptor longus, and then pectineous is in the same plane as adductor longus, and then pectineous is in the same plane as adductor longus, and then right behind that uh is going to be adductor brevis. And behind that is going to be adductor magnus, but the thing that's--that will tell you exactly which is brevis is, of course, the obturator nerve is going

to split on each side of it. And those--uh post--the posterior branch generally gets uh the obturator externus as well as the uh adductor magnus. Oop! It doesn't get that, but that's uh that's gotten by the uh tibial nerve. There's another muscle that runs--runs along here. We'll just draw a line. It's called the--the gracilis, a long slender muscle. And the uh the anterior branch is going to come out and innervate that as well as uh as uh adductor longus.

A: . . . .

L: And in--in the majority of cases, pectinous. In some cases, pectineus may be innervated by--by the femoral nerve, but in almost all cases it's gotten by obturator nerve. Of course, we could put down the obturator artery that--that runs with this and has a similar--similar course.

A: . . . go over. . . .

L: Okay. As soon as the--the obturator nerve uh leaves the obturator canal through the obturator foramen, then it splits into anterior and posterior branches. And these are located on either side of the adductor brevis. The posterior branch uh gets external--obturator exturnus and adductor magnus. Uh the anterior branch generally gets gracilis, longus, pectineus, and the brevis may be gotten on--either way. But the idea is that this territory--so the medial side of sartorius is adductor and obturator nerve territory, and this stuff

lateral is femoral ter-territory, this muscle wall. Uh the adductors uh obviously, are strong AV ductors because of--of the thigh. That is, they pull the thigh medially or toward the other thigh. Uh it isn't really clear exaclty what they do as far as uh gait. Uh mostly they probably stabilize the thigh and the trunk in an anterior uh medial-lateral uh position. That is, uh when you stand on--on one leg, certainly adductors are going to work, but then the AV ductors are down here, and we'll talk about those Thursday. Uh but the medial group, uh the uh AV ductors uh probably just stabilize the pelvis in that frame. It's interesting that uh with arthritic hips and painful joints and that sort of thing, or with dislocated hips, the uh adductors tend to go into spasm uh for some reason. And in that case uh as well--as well--as well as other--there are a lot of central nervous system conditions where you get adductor spasm. Of course, if that occurs, then the legs tend to scissor, or they tend to fold across like this. And they've found, particularly in--in older people that have painful hips or--or where they--they've transplanted or clipped in uh prosthesis for the hip, that they can go in and actually clip the nerve to the--to the adductor group. And they seem to walk just about as well as they ever did. But in that age group, they aren't going to run or do anything very athletic.

A: . . . .

L: They uh they seem to get along almost as well without uh this large adductor mass as they did before. And, certainly, it elminates the spasm and that sort of thing. So, I guess I'll uh quit for today.

APPENDIX F
MEDICINE 2

(L: Lecturer; A: Audience)

L: We have a new wrinkle this morning in that Nellie Sieller is going to tape this lecture, and then what-- you're analyzing technical jargon, is that uh--

A: Subtechnical.

L: Subtechnical jargon. So uh we're all being made part of posterity this morning. All right. So I want to uh continue what we started two weeks ago, uh talking about the segmental uh neuromuscular system as a model for uh as a model system, taking into account uh the sensory aspects, the integrative aspects in the spinal cord, and the output aspects, uh neuromuscular uh transition. So we will pick up where we left off. Can I have the projector on, please? Is that adequate light for most purposes?

A: . . . .

L: All right. So the general topic I want to take up today is the basis of motor control at the segmental level, and by segmental level uh I mean uh spinal cord levels. Remember I talked the first week about the various uh uh levels, C-one, C-two, and C-three, and so forth. So that's what segmental motor control

refers to is input and output at a particular level or limit of uh uh levels of the cord. It does not include descending input from uh uh superspinal levels, brain stem, uh cortex, basal ganglia and so forth. And so, there's sort of--at this point, there are essentially two schools of thought on uh sort of the organizing principles of uh segmental motor control. One is that motoneuron size has a very strong role to play in uh in the recruitment order of motoneurons. Now that is the order in which motoneurons are recruited. And another point of view is that motor unit type is sort of uh a basic uh organizing principle. Uh and I will take up the protaganists of these uh uh points of view forthwith. This is a slide from uh a paper by Elwood Henneman, which he published back in nineteen sixty-five, and which is also in uh the Mountcastle uh textbook uh references that I gave to you. Uh this is a very famous uh piece of work upon which Henneman um developed a whole uh the whole idea which he refers to as the size principle. And the experiment was done this way. These are recordings from cut ventral filaments of a cat, uh an anesthetized cat, and these--uh the ventral roots have been cut and small filaments put up on recording electrodes so that you can record action potentials. And these--the--the line up here--what--what was being done was a muscle was being stretched, and as that muscle was being

stretched, then the uh stretch receptors, primary and secondary stretch receptors, would be activated, and they would send action potentials into the--into the spinal cord uh which in turn would synapse on motoneurons going back up to these cut ventral root filaments. So the situation you have, diagramatically, is something like this. The spinal cord, the muscle out here, stretch receptors in the muscles going into the spinal cord, ending monosynaptically on motoneurons. Uh and now this is a ventral root, and we have maybe several dozen uh axons from spinal cords in this cut ventral root, and the cut ventral root, then, is up on recording electrodes, and we're recording the uh action potentials in those individual uh axons, and that's what we see here. And the muscle is being stretched. Uh and the more you stretch it, the more you excite the afferents, the more input you have. And the uh distance between these two lines designates the amount of stretch being placed on the muscle. So that's this uh calibration here. Uh if they're that far apart, it's a four kilogram stretch. At this point there is no--uh the lines are uh overlapping each other so there's no stretch, and then we start to stretch it. And what you see is that recording of ventral root filaments. First you see action potentials from one uh axon here, all the same size and occurring at regular intervals. And then as you increase the stretch, that first one still

is popping along, but now a second one comes in, and this Henneman calls number two. And then you add more stretch. One and two are still there, but now you see a third one, even bigger, and then you add more stretch. One, two, three are in. Also, now four and five come along. So now with the maximum amount of stretch, we have all five uh axons firing. And if you reduce the amount of stretch, you find that these axons derecruit in the reverse order. First you have five, four, three, two, and one. You reduce the stretch. You have four, three, two, and one. Less stretch, you have three, also two and one. Less stretch, you have two and one. Less stretch, you have just one, and then you go back down to the initial situation. So the way Henneman interpreted this was that the size of the action potential is related to the size of the axon. And the size of the axon is related to the size of the cell body. So his interpretation was that as you increase the synaptic drive on the motoneuron pool, you recruit motoneurons in order from small to large. The smallest having the smallest cell body, the smallest axons, and making the smallest action potentials, and so forth on up. And he created a very elaborate scheme out of this um along the lines that the small motoneurons would have small, slowly conducting axons, and they would go to small muscle units uh which would be very weakly contracting in the muscle. And as more

synaptic drive was added, progressively larger motoneurons with faster conducting axons and connecting to larger muscle units would be recruited and so forth on up. And he con--he hypothesized that there was probably only one order in which motoneurons could be recruited, from small to large, and that this uh sort of organized the pool in a very practical way because the small muscle units are the ones which are least fatigable, but those are the ones that are going to be used the most. So that fits very nicely. They're going to be called into action early, but since they don't fatigue, that doesn't matter because they can fire along all day. The bigger, very powerful units which you just bring in in sort of an emergency situation are rapidly fatiguing, but again that doesn't matter because you don't use them very long. Those are going to be the last ones to be recruited, the first ones to be derecruited. So the fact that they fatigue rapidly is not particularly important. So uh Henneman put out a series of about five papers in the Journal of Neurophysiology back in nineteen sixty-five, developing various aspects of this. He also looked at descending influences. Uh he caused cortical seizures in some of his animals, and showed that the recruitment order you get from that descending input still appears to be the same. He looked at uh inhibitory inputs into the motoneuron pool and uh came up with uh some similar

sorts of uh observations there. And he built a whole uh whole model system on this very simple concept of size. So, uh the size principle which is attributed to Henneman, and pretty much goes hand and glove. You can hardly say "Henneman" without saying "size principle." You can hardly say "size principle" without--without saying "Henneman." Uh in--in Mountcastle's Physiology in nineteen seventy-four, he made this statement, "It is the size of the motoneuron that determines its threshold and relative excitability." And he was very explicit about determination at--at that point. Uh he published another article in this book in nineteen seventy-nine in which he said, "The neural energy required to discharge a motoneuron, the energy it transmits and releases in the muscles, its mean rate of firing, and even its rate of proten synthesis are all correlated." So it looked as though in this five year period from seventy-four to seventy-nine that he had altered his uh his feelings a big and gone from determination to correlation, as though uh he has sort of weakened his uh his resolve in this regard. Uh but I guess he didn't mean it. Because in nineteen seventy-nine, he also put out a paper in uh in Nature, along with Luscher and Ruenzel, uh and which he entitled "How the Size of Motoneurons Determines Susceptibility of Discharge." So, I guess his uh feeling of correlation was uh just a momentary abberation. Uh

that, however, raises the question which we take up here, why should small motoneurons be recruited first? I mean, it's all well and good to say that they are, but it seems like you could come up with some sort of mechanism by which that could happen. And that brings us to a consideration of cell size and input resistance. Input resistance refers to the resisted load that is presented to a microelectrode inserted into a motoneuron. I'll try to explain that in this slide. These represent two spheres. One of which has a surface area twice the other. And these spheres are supposed to be a uh a model of a neuron. And the neuron membrane uh can be though of as made--being made up of little patches of membrane, each of which has a specific membrane resistance. And just for simplicity, then, I have pictures this sphere uh as being made up of two patches of membranes, uh and each one has the specific resistance of two. And the value two there is so the numbers work out uh conveniently. There's nothing uh significant about that--uh the magnitude in itself. And I haven't given the units to it either, but that doesn't matter. In this case, we have twice the surface area. Therefore, we have twice the patches of individual membranes. And if we assume that the specific membrane resistance is still two for each patch, since we have twice the surface, we have twice the number of--of resistors. So, in this case, we have

four of them, and the equivalent uh circuit for this would be four uh two-unit resistors in--in parallel. The equivalent circuit for this would be two two-unit resistors in parallel. You may or may not remember the formula for the net resistance of this circuit, of resistors in parallel, is one over R total equals the sum of the reciprocals of all the individuals. So uh--hello--if you were to work out this equation for these values, you'd come up with a value of RN, and RN is the uh abbreviation which is used for input resistance. Uh RN would be one in this case. Uh since I've chosen values to make it come out that way. In this case, where we have twice the number of resistors, and, therefore, twice the number of current paths that our injected current can take, uh this works out to an input resistance of point five. So the more resistors in parallel we have, the more paths our current can take, and the less net resistance we have across that whole uh ensemble. And so the important thing here is that as the surface area goes up, the input resistance goes down, and it's a reciprocal relationship. Now this, you will recall, is Ohm's law. And that's a very useful sort of relation to have in all of this for the following reason. If we inject a current of value one into this cell, and look at the voltage which is developed across these resistors, or across the membrane uh from inside to out, uh from Ohm's law, uh

if the I is one, the current is one in this case, and the input resistance is one, which we've worked out here, then the voltage developed across the membrane is one. In this case, if we inject that same current of one uh into this cell, we have half the resistance, and, therefore, one times point five is going to be point five. And so we're going to develop half the voltage across this cell as we did across this cell injecting the same current. So a practical value of this is that we can get a relative measure of the size of these cells by injecting a current into them and measuring the amplitude of the voltage generated by that current. And this is a technique that uh we use in the laboratory. Uh since we can't anatomically measure the size of every cell that we record from, we can get an idea of how big they are by measuring their input resistance. Now there are a couple of ways to do that. One is to have two microelectrodes uh in the same cell which is possible, and people do do it, but it's--it's difficult. In that case, you inject the current through one and uh measure the voltage through the other. The more practical way that people use is to use a bridge circuit in which you use one microelectrode to simultaneously inject the current and measure the voltage. Uh we won't go into the uh circuitry of that, but it's a--it's a very accurate technique. All right, so that's this important relationship between cell size

and input resistance, and--but now how does that move us toward the size principle? Here, I've pictured three different cells whose surface areas are in the ratio of one to two to four. One. Two. Four. Um and based on what we saw in the last slide, the input resistance of this arbitrarily we can take as one. Since this has twice the surface area of that, its RN should be a half. And since this has twice the surface area of that, its surface area should be half of that and a quarter of that. So now we have three cells um with surface areas in the ratio of one to two to four, and input resistance in the ratio of a half--of one to a half to a quarter. Now if each of these cells is terminated on by one bouton or two boutons or five boutons or what--it doesn't matter how many, but as long as it's the same number in each case. Uh let's just use one for simplicity. We could say that each of those boutons in--when it's activated, injects a synaptic current whose value arbitrarily we will call one. And going back to Ohm's law, uh the voltage developed--or the postsynaptic potential developed by that--the injection of that current is going to be in the ratio of I times R, or one times one. So, in this case, we'd have a postsynaptic potential with a value of one. In this case, we're also injecting a current of one because we have one bouton, but we have half the input resistance, and, therefore, IR value, or voltage

value, our postsynaptic tension is going to be a half. In this case, we have four times the surface area, one-fourth the input resistance. Synaptic current is the same absolute value, and our IR value is going to be point two five. So, if we have the same number of boutons, and they are--they all are equally efficacious, that is, they all inject the same amount of synaptic current, and a lot of other assumptions, uh we should have an inverse relationship between the size of the cell and the amplitude of the postsynaptic potential developed. So, in this kind of situation, then, we would predict that there would be a size principle. The smallest motoneuron um would develop the largest postsynaptic potential and should be the first recruited. The biggest motoneuron should develop the smallest postsynaptic potential and should be the last recruited. That's if we have equal numbers. And uh Henneman was able to uh go through uh various anatomical and physiological literature and suggest that that may actually be the case, that the uh the one-A afferents, for example, may uh contribute equal numbers of terminations to all motoneurons. And, therefore, you'd get this predicted relationship. At the other end of the uh spectrum, it might turn out we have equal densities. Uh so, for example, here's a small cell having only one terminal. Here's a cell twice the surface area having twice the number of

terminals, and here's a third cell with four times the surface area having four times the uh number of terminals. And you can see what's going to happen here. These--the surface area and the input resistance are going to be the same, but the injected synaptic current is going to go up because the number of terminations is going to go up. And so applying Ohm's law here, we find that in each case we get the same size postsynaptic potential. Uh and, therefore, there would be no preferential reason, at least based on the size of the input, for any one of these cells to be recruited first, and, therefore, we would not have the size principle in the case where there's an equal density of terminations on all of these cells. Uh and that analysis will be important a little bit later in the things I talk about. So anyway, that's sort of the uh the nuts and bolts of Henneman's size principle. It got elaborated in much more detail and lots of additional experiments, some supporting it, uh some denying it, but essentially it was based uh on this uh principle of the relationship between input resistance and cell size, and assuming equal numbers of terminations and not equal densities. Uh an alternative view of uh motor pool organization came about through work of Robert Burke, R.E. Burke at the NIH, and the statement that he made in nineteen seventy-five in a publication was that it "seems more appropriate to view

the size principle as a convenient shorthand that conveys a good deal of correlated information rather than as a universal and inflexible rule predicting the output of a motor unit pool under all conditions." Then he sort of said that the size principle is handy as a way to remember certain things, but it probably doesn't have any particular uh mechanistic importance. And, so let's develop those ideas, and see if we can come to any resolution on this. So these next few things, then, will take up the roles of motoneuron size and motor unit type in uh in segmental recruitment. This fairly complicated slide uh lays out the basis of Burke's motor unit type uh system. A motor unit consists of the cell body, the motoneuron, cell body, and its dendrites, also its axons and the individual muscle fibers within a muscle that are innervated by that axon. And there may be four or five or six hundred individual muscle fibers in a uh muscle innervated by one motor unit. And this is sort of the--the quantum aspect of the nervous system in that uh whe--the output of the nervous system--when this axon fires, all of these little branches fire, and all of the individual fibers contract. So it's an all or none uh activated system. Burke came up actually with four different categories, three of which are shown here. Um first of all, he classified his motor units into fast and slow. And this was based on the

contraction time of a single twitch. So, if--if you were to activate that axon and cause all these muscle fibers to contract, and you were to look at the time it takes for that contraction to develop, uh what you find is that many, many of these cells will achieve their full contraction in less than thirty-five milliseconds. And there's another group that are very slow contracting that can go out to a hundred and fifty or so milliseconds, and so the F, initial F here, and that initial F here, and that S refer to fast and slow contraction times. Fast being those muscle units that con--have a contraction time thirty-five milliseconds or less and slow referring to those that have a contraction time of thirty-five milliseconds or greater--thirty-six milliseconds or greater. Uh it also turns out that uh these fast contracting units tend to be much stronger than the slow contracting units. There is some overlap, but by and large uh the slow contracting units are extremely weak, down around a one gram twitch, or a half gram twitch, or a quarter gram twitch. Whereas uh the twitches of these fast contracting units may go up to forty or fifty grams. That's a single muscle unit. Well, that's one aspect of the classification scheme, that is, speed of contraction. The other aspect of the clas--of the cla-sification scheme has to do with resistance to fatigue. And the way that Burke studied this was as follows. He would activate the axon by one

manner or another. And with a burst consisting of thirteen stimuli over a period of about three hundred thirty milliseconds, and then it would be off for six hundred and seventy milliseconds, and then he would give another tetanic burst of uh going on for three hundred thirty milliseconds, and then off, and so forth. Uh this is a--works out to a forty hertz stimulus, and this is continued for two minutes. And when you activate this uh axon that way, what you do is tetanic contraction of the muscle fiber, and if you were to record muscle fiber contraction, you would see this sort of thing, contraction and relaxation, contraction, relaxation, and so forth. So these plots down here are the envelope of those contractions on a very slow time base. This is two minutes. Uh and so on the first--during the first tetanic contraction, you get uh the full strength develop. Then it relaxes. Then it goes up again, relaxes, up again, relaxes, up again, relaxes. But what happens is that with these very uh powerful units that are unable to sustain this contraction, and so the envelope starts to drop, and at the end of two minutes, you may get virtually no contraction at all of that muscle unit. In fact, it very often happens much earlier than that. Uh out around thirty or forty seconds. Uh you find that this starts to wane, and by the time you get out to about two minutes, you have no contraction at all left.

Um the slow units do not fatigue. You--you can--you can uh give them this tetanic stimulus for hours, and they go cracking along. They--and their contraction at the end of an hour will be just as strong as it was at the beginning. So Burke came up with a classification scheme based on this. And what he did was to take the strength of contraction at the end of two minutes as a fraction of that at the beginning of the two minutes. So, if you had, say, a one hundred gram uh contraction at the beginning, and a two gram contraction at the end, then the fatigue index would be two over one hundred or point oh two. And that's--that's a--a likely value for one of these fast twitch, fast fatiguing. The second F here, then, stands for fast fatigue. So his overall scheme, then, was to compute what he called the fatigue index for a motor unit. And using cut points of twenty-five percent and seventy-five percent, if at the end of two minutes the contraction strength is twenty-five percent or less what it was at the beginning, then those are FF motor units, and it's fast twitch, fast fatiguing. If they're seventy-five percent or greater, they are FR motor units, or fast twitch, fatigue resistant. And this is an example of one of these that showed uh some fatigue, but it was still at seventy-five percent of its initial value. And then there's a--sort of a small group in the middle here, which he referred to as F-intermediate.

Uh and it may be that these are actually units in transition because with the training effects, for example, you can move a unit from one category to another. Uh long distance runners, for example, have a lot of FR units, uh fast twitch, fatigue resistant. Uh they develop the uh the oxidative capacity of their muscle fibers much greater, and they can uh get a much better endurance. On the other hand uh, weight lifters who don't need much endurance but need great power for short uh for short periods develop a great uh preponderance of FF units in their uh in the muscles they use for uh uh for weight lifting. Not much endurance, but uh good--uh but great power. Uh so this is Burke's classification scheme uh as far as the fast twitch units are concerned. The slow twitch units all have a--a great resistance to fatigue so that it would not really be appropriate to put them on this plot because they're all--they all have fatigue indexes of seventy-five or better. In fact, usually they're up around a hundred or even greater than a hundred because they often potentiate. They often are contracting more strongly at the end of two minutes than they are at the uh at the beginning. So, that was--this is--I guess you don't see it as an alternative to uh the size principle at this point uh, but we will develop that uh idea forthwith. So this is a uh a little summary of the distribution of these

various motor unit types in the medial gastrocnemius muscle of the cat which is a muscle--muscle which is greatly studied for many reasons. It is called a heterogeneous muscle because it has motor units of all four types. Uh roughly twenty-five percent--well, say there are about two hundred and eighty motor units in the medial gastrocnemius muscle, two hundred eighty medial gastrocnemius motorneurons, and, therefore, two hundred and eighty motor uh units. But a quarter of those are type S. A quarter of those are type FR; around five percent are F-intermediate. Another forty-five percent are FF. Uh I didn't go into this classification scheme here, but that refers to the--the uh enzymatic makeup of the muscle fibers. Uh O refers to oxidative. G refers to glycolitic. And the slow twitch muscles uh and the fatigue resistant muscle fibers uh have a lot of uh oxidative enzymes in them, and, therefore, they depend on uh a uh an intact blood supply for their uh energy supply, but it can be continuously uh replenished. Uh the FF's uh have no or practically no oxidative uh enzymes in them. They have glycolitic enzymes, and so once they use up their uh glycogen store, then they uh have to take a day out to replenish them. Uh so they can--over the short period, though--they can uh function in the absence of a uh of the blood supply, but they can't replenish it as quickly. Contraction times are about the same for all

of these. The mean's around twenty-five milliseconds, but by definition they can go up to about thirty-five. The mean for the S's is around sixty. Uh their range is uh from around thirty-five to well over a hundred. Fatigue resistance is given here. That's actually part of the classification scheme. Uh the tetanic tension that can be developed by these various motor units. Uh the S's are uh very, very weak. The FF's are uh very powerful, but, of course, these can't sustain their contraction very long. Uh and in terms of the total tension developed by the muscle, uh even though the S units comprise twenty-five percent of the pool in terms of numbers, they only contribute about four percent of the uh total tension of the muscle. Uh the FF's uh are less than half numerically, but of the total power that can be developed by the muscle, they contribute around seventy-five percent. So how is this uh information used experimentally? This diagram is a uh--is that focused? I don't have my glasses. This diagrams the experimental sk--uh set-up that's uh more or less routinely used. The gray matter, the spinal cord, the motoneurons, uh micropipet inside a motoneuron, the axon going out to a muscle, and the terminations of that axon in--in muscle fibers. And you can electrically stimulate out here, and gen-generate an antidromic action potential. And by measruing the time it takes to get there and the distance it had to travel

to get there, you can calculate the uh conduction velocity which gives you some idea of uh axon size. Um you can also inject current into here and do a couple of things. One thing, by injecting the current with bridge circuit, you can look at the voltage generated and get an idea of the size of this cell, the input resistance that we talked about before. And you can also inject current here and see how much current is required to bring that cell to threshold, get some idea of its excitability, and the term that's used there is rheobase. And I will develop these things at this point. This is the method that's used to measure input resistance or one of the methods. There are actually several. Uh what one can do is to inject a current of one nanoamp, ten to the minus uh ninth amps, and use a prolonged uh square wave. In this case it was fifty milliseconds. Uh and using a bridge circuit, look at the voltage generated across the cell membrane by that current. And if you remember the uh talk that uh George gave a couple of weeks ago, uh he described the charging and discharging of an RC circuit, and that's exactly what you see in a motoneuron. Since the membrane has both resistive and capacitative elements to it, you would expect it to show charging and discharging curves uh uh typical of an RC circuit, and that's just what you see. But if you wait for the uh voltage to develop fully, then the capacitance is all

uh discharged or the capacitor is all charged up, I guess is a better term. And what--in that case, then--is a steady state uh membrane resistance, and if you inject a uh a calibration pulse, uh you can simply use Ohm's law relationship of E equals IR. And the ratio of that amplititude to this amplititude works out to be the membrane resistance in megohms. Uh so what we have, E equals IR uh. I is ten to the minus ninth, and E is uh ten to the minus third. Uh so that gives us megohms. Uh in this case, this was about twice that, uh and, therefore, uh this is probably around a two megohm input resistance cell. And uh that number at this point won't have any meaning to you, but uh if you do enough of these and look at some other characteristics of this cell, you can get some idea of whether there is any sort of a relationship up between the cell size and, for example, the various uh motor uh unit types, and see, as a matter of fact, how this relates to uh Henneman's idea. So that is measurement of input resistance. Another thing that one is interested in is the uh the excitability of the cell, and you can--you can uh measure that by injecting a current intercellularly and increasing the magnitude of that current until you just fire the cell. Now, these are four separate places in which a current of twenty-six nanoamps was being injected for a period of fifty milliseconds. And in this case an action potential was

fired out here. In this case, we were just below threshold and no action potential was fired. In this case, it was fired again. In this case, it was fired again. Every time the current was the same. So we're very, very, very close to the threshold for this particular cell. And so the value of twenty-six nanoamps was assumed to be the rheobase current of this cell. You could tweak it up a tenth or down a tenth and uh get something more precise if you want, but uh for practical purposes, this is fully accurate. So then that defines the uh excitability of the cell in operational terms. Another thing you can see here is that after the action potential is fired, there's a long after-hyperpolarization here, and that happens in every case. And it turns out that's that very characteristic of different kinds of motor units. Uh that--that lasts for different durations in different cells and probably has some functional significance which I will take up uh a little bit later. All right. So that's--those are the techniques for measuring input resistance and rheobase. Uh another thing you can do when--with a microelectrode in here is to inject trains of current or single pulses and cause a muscle twitch by activation of that motor unit. And then, using a strain gage, you can measure the uh properties of--of the uh of the twitch and get an idea of contraction strength, fatigability, uh and some other more subtle

measures that are made. And so that would be a technique, then, uh determining motor unit type of this motor unit would be to inject current, look at the twitch contraction time, um look at the fatigability, um and that we will--we will do next. No we will not do that. Uh this is sort of a summary diagram of where the rest of this lecture is going to take us. And it seems appropriate to sort of tell you where we're going and then get there. Uh so you sort of fit things in as we go along. Um the motor unit pool can be thought of as being made up of three or four individual motor unit types: type S, type FR, actually F-intermediate in here, and type FF. And by making measurements of input resistance, it turns out that the smallest motor units are the uh the smallest motoneurons are the type S. The largest motoneurons are the type FF's, and the FR's are intermediate, at least based on measurements of input resistance. There's also now some anatomical evidence uh that suggests the same sort of thing. Maximum tetanic tension develops in the same uh direction. The type S are the weakest motor units. The type FF are the strongest, and the FR's are intermediate. Rheobase--or um excitability is in this direction. The S's turned out to be the most excitable, have the lowest threshold for being activated by injecting current. The FF's are the least excitable. They take the most injected current to uh

be excited. And uh FR's are intermediate. And somewh--some EPSP's, this is those EPSP's generated by one-A spindle afferents are the smallest in FF's and the largest in S's. So the conclusion that's going to come out of this is that the S's are probably the first ones to be recruited because they have the lowest rheobase and because they have the largest EPSP's. And the FF's are going to be the last ones to be recruited because they have the highest rheobase, and they have the smallest EPSP's. Uh and over a population, this is going to be consistent with what Henneman said, that the S's are the smallest, but I'm going to give you evidence that size is not playing any causal role. That isn't the cause of why these are the first ones to be recruited. That is simply a sort of a coincidence. Uh so that's the uh that's the message, and uh if any of you have had a chance to read any of the references uh that were named, the one--the Sypert and Munson reference that came out in Neurosurgery this year developed this same idea. So if I obscure it for you today, you might want to read through that and try to make some sense of it. All right. So how do we get to that conclusion? All right. These are--this is the classification scheme that Burke used, and these are the data from our laboratory as they fit into that classification scheme. We took individual motor units, and uh determined their fatigue index, and determined

their contraction time, and fit them into this scheme as shown. Those with a fatigue index less than twenty-five percent are the FF's. Those between twenty-five and fifty are F-intermediates, and those greater than seventy-five are fatigue resistant, but we also have a cut about thirty-five milliseconds compaction time. The FI's and the FF's all have contraction times, with occasional exceptions of thirty-five milliseconds or less. So there's no problem in classifying those. However, the fatigue resistant group that is made up of FR's and S's do appear to more or less form a continuum. You have some out here with very long contraction times, and you have some in here with relatively short contraction times. So this thirty-five milliseconds is in a sense sort of arbitrary. Uh but it sort--it is pretty much agreed upon by people that uh there are differences between cells, uh and it more or less corresponds to the thirty-five millisecond contraction time difference. So this is the scheme that was used anyway. And uh things get sort of circular in here, but uh I think you will see that using this classification scheme, we can show some pretty profound differences in other aspects of motor units which go along with these uh quadripartite uh classification. So, the first thing that we looked at was the conduction velocity of the axon of the motoneuron. Very simple thing to look at

as I said. We just stimulate up near the nerve, cause an antidromic action potential, and look to see time and distance. And it turns out that the--all of the fast motor units have conduction velocities that are indistinguishable from each other, all right around one hundred meters per second. Whereas the slow motor units have conduction velocities down around ninety meters per second. So, you're saying so what, and I will try to uh tell you so what. Uh we also looked at input resistance of these various motor units and found that the highest input resistance was in the S's. The lowest input resistance was in FF's, and the FR's had an intermediate value. Sort of ignore these because the numbers are very small. So, if you remember, we said that there's an inverse relationship between input resistance and cell size. And since the S's have the highest input resistance, they should be the smallest cells. Conversely the FF's, having the lowest input resistance, should be the largest cells. Um so Henneman, remember, said that uh small cells have small axons and, therefore, have um uh slow conduction velocities. And sep-separating the F's as a group from the S's, we see that that would hold up because these are the smallest cells and have the uh slowest conduction velocities. And you get up within the F group, though, things get more complicated in that this difference was significant. We had significantly lower

input resistances for FF's and, therefore, presumably, significantly larger cell codies. However, there was no significant difference in the uh conduction velocity as a group. So that suggests that the axon size for all the F's are pretty much the same. Yet the cell body sizes are not the same. Um and this sort of contradicts a rather long held belief in um in uh neuroanatomy and neurophysiology that there is a very close relationship between uh cell size and axon size. And having come up with these results and looking through the literature, one can find other examples that support this. So it is probably the case that that close relationship really does not exist. On a population it does. Uh separating F from S, but--but within the fast group it does not. We also looked at rheobase, and these are--are the values that we got for rheobase measurements by our various motor unit types. The S rheobases are down around five nanoamps. The FF rheobases are up around twenty nanoamps. The FR's are somewhere in the middle, usually around thirteen or fourteen nanoamps, as a group. So that tells us, then, that the S uh motoneurons are the most excitqble, might be the first ones to be recruited. Um so some of you are probably putting two and two together here, and saying that, okay, the S motor units have the lowest rheobase, and they have the highest input resistance. So maybe what is going on here is simply a case of

Ohm's law. That uh rheobase is uh lowest here because input resistance is highest. And, therefore, a given current across that high input resistant cell would generate a large voltage and bring these motor units to uh uh threshold easily. And the opposite for these. And so if that were the case, you would expect to see a very close linear relationship, inverse linear relationship, between uh input resistance and rheobase. So the next--uh we took that question up, and this is a plot of data. F meaning an FF. R meaning an FR. S meaning an S. And this shows the relationship between rheobase and input resistance for all of these cells. And when you first look at it, you see the very relationships that you thought might be there, high rheobase for low input resistance cells. And that--so seems sort of neat. And maybe uh old Professor Ohm was right. However, if you look more closely at some of these data, and take a group right here, for example, with a range of around point nine to around one point three megohm input resistance, what you see is that all of the FR units have a higher rheobase than all the S units right in here. Now, if input resistance was determining rheobase in an Ohm's law type relationship, then you would expect these all to be mixed up, if the only cause of rheobase is input resistance. But they aren't all mixed up. They're very nicely segregated. If you look over here, uh you can find an area where the

FR's tend to be lower than the FF's even though the input resistance range is the same. There is some overlap in here. It isn't quite as neat as this little case turned out to be. But, by and large, within that uh common range of around six to nine, the FR's are certainly lower as a group than the FF's. So, again, it looks as though input resistance can't be the only determinate of rheobase, or they should all be covering the same uh range of values. So on an intuitive basis, uh you begin to wonder if input resistance really is determining rheobase. There's a more uh rigorous way of going about it which is to use an analysis of covariance. Um and that is depicted here. A and C are two different possible schemes by which the relationship between rheobase and input resistance may exist. Uh this scheme would say that input resistance is the determinant of rheobase, and this line would represent the uh relationship between them, and the populations of FR's--of FF's, FR's, and S's lie along that uh common line. Their rheobases are different because the input resistances are different. So that's one possible scheme. Another possible scheme is that there really is no relationship between rheobase and input resistance. That is, this would be a uh line whose uh slope is zero. But these uh somehow by their nature have rheobases and input resistances, some of which overlap, and they just

happen to lie in that uh same sort of relationship. Uh the way the analysis of covariance works is uh you use a least squares procedure to calculate the relationship between the two variables for each group. So you take the uh FF's and uh you get the regression between rheobase and input resistance. Same for the FR's and same for S's. And then using that relationship, you ask, "What would the rheobase value be if we were to adjust the input resistance so that we have one common input resistance?" So this X on the dotted line represents a common input resistance. And we've used the least squares relationship between rheobase input resistance to adjust rheobase uh assuming a common input resistance for all those groups. So, if this were the real situation, and we adjusted rheobase to the common input resistance, then we'd have only one population. It would all collapse into one. On the other hand, if there is no relationship within groups, and we adjust the uh mean input resistance to an overall mean and look to see what happens at rheobase, uh then these differences would persist because we're just sliding them that way rather than that way. And this is, in fact, what analysis of covariance of our data showed. That when you adjust all the uh input resistance to a common mean, you still are left with differences of rheobase. And so that suggests that uh there are characteristic differences of rheobase by

unit type that are not caused by any relationship which may exist between rheobase and input resistance. And so it apparently is a characteristic of the motoneuron itself by virtue of its being an FF or FR or S. Precisely what the neur--the uh cellular mechanism for this is--is uh wide open at this point, but the uh--but at the descriptive level, anyway, that seems to be the way it is. So to sum up these properties of motor unit that we have discussed so far: For conduction velocity, the S's are slower than the FR's and FF's which are equal. In put resistance: The S's are greater than the FR's which in turn are greater than the FF's. Rheobase current: S is greater than FR is greater than FF, and rheobase current is a function of motor unit type much more so than input resistance. In fact, it may end up being not at all related to input resistance. I didn't take up after-hyperpolarization. That's that long, slow hyperpolarizing uh event that takes place after the action potential. And the S's are much--have a much longer after-hypoerpolarization than do the FR's and the FF's. Um something I might mention that is probably of functional significance to the after-hyperpolarization. Uh the rate uh that it takes for a muscle unit to fuse into a fused tetanus is very different for fast and slow fibers. That is, a slow motor unit will generate a fused tetanus at a much lower frequency than it takes for a fast motor

unit to develop a fused tetanus. I think I said that in English, but uh uh. So if--if you give a tetanic burst to a slow motor unit, uh you can bring it to uh a fused tetanus. It would take a much higher rate in a fast motor unit to bring it to fused tetanus. Now the after-hyperpolarization is this long slow hyperpolarization after an action potential, and it limits the rate that a motoneuron can fire. And so the maximum rate that a slow motor unit can fire is much slower than a fast motor unit because of this after-hyperpolarization. But that very neatly matches properties of the muscle unit because the muscle unit does not need a high rate to fuse if it's a slow motor unit. Uh so that's one aspect that uh seems to be very neatly uh matched. Another aspect that I didn't take up here has to do with accommodation. And accommodation refers to the fact that if you give a long steady depolarization pulse to a motoneuron, it may or it may not continue to discharge action potentials. If it does not continue to discharge action potential, it's referred to as <u>accommodation</u>. And it turns out that fast motor units, particularly the FF's show much more accommodation. So uh uh even though they have a sustained excitatory drive, they may not continue to discharge, and that sort of fits their functional properties because they fatigue very rapidly. Um S motor units show no accommodation. In fact, they may

even show a sort of a negative accommodation in that once they start to fire, they activate an inward--inward calcium current, I think, kind of thing that tends to make them go regenerative. So it may be that the S's, once they start to fire, are sort of self-sustaining. But that's fine because they don't fatigue. The FF's on the other hand, for a given synaptic drive, may actually decrease their rate uh which is something that they need because if they keep firing and they go into a fatigue. So there's some nice matches between the properties--membrane properties of the cells and the mechanical properties of the--of the uh muscle units.

A: . . . .

L: Teleologically, that's what you'd say, yeah, but the--but accommodation of the motor units--of the motoneurons keeps it from firing at higher rate, and, therefore, keeps its muscle unit from fatiguing.

A: . . . .

L: Right. Right.

A: Okay.

L: Why don't we take five at this point. Uh let you catch your breath because it goes sort of into another aspect of this in the next part and uh.

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